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BASIC REQUIREMENTS FOR MANUSCRIPTS

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Journal of the
SANITARY ENGINEERING DIVISION
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THE SANITARY ENGINEER OF THE FUTURE

Theodore F. Hatch*
(Proc. Paper 1168)

ABSTRACT

The rapid expansion of technology is creating a widely diverging field far from that of the original civil engineer. The sanitary engineer must expand his knowledge in the newer aspects of technology where they affect the environment of man. The future sanitary engineer will meet these new and varied problems.

Sanitary engineering is an area of engineering specialization concerned with: (a) design, operation and management of engineering structures and projects, developed as a whole, or in part, for the protection and promotion of public health, particularly as these are related to improving man's environment, and (b) investigating and correcting engineering works and other projects in the course of design or after completion, which are capable of injuring public health by being or becoming faulty (in respect to impact upon man) in conception, design, operation or management.[1] There is an important difference between these two areas of activity and responsibility. The first has to do with improvement of man's environment through the deliberate and direct use of engineering structures. The second involves a professional responsibility to make certain that the creations out of technology, designed to benefit man in other ways, and in this respect meeting all technical requirements successfully do not, at the same time, cause injury to health.

In its strictly physical aspects, sanitary engineering draws upon specialized areas of physical science and technology, but in this sense, it is not different from other engineering specialties which are also built upon detailed knowledge in particular fields of applied physical science. Of greater

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1. Committee on Sanitary Engineering and Environment, National Research Council.

significance in distinguishing between this and other branches of engineering is the special responsibility of sanitary engineers for the protection and promotion of health through engineering procedures. Success is measured in terms of human reactions whereas in other branches of engineering, accomplishments are evaluated in terms of the physical performance of the structure itself.

Thus, sanitary engineers deal with the physical and biological stresses, and, in its broadest sense, with the social stresses of the environment and their impact upon man. In order to design or operate engineering works to bring such stresses within safe tolerance limits for man, it is obvious that the sanitary engineer must possess considerable knowledge of the ways in which man responds to environmental stress and, in the course of design and operation of engineering works, he must draw upon rather detailed understanding of stress-strain relationships which fall outside the ordinary areas of engineering skill and responsibility.

Sanitary engineering had its beginnings in the early days of attack upon communicable diseases and has operated with great success upon those diseases which are spread from the source of infection to man through the environment. By studying the behavior of the causative agent during its passage through the environment, sanitary engineers, working jointly with biologists, physicians, statisticians, and epidemiologists, discovered its modes of travel; they gained knowledge of its ability to survive in the environment; they found the most vulnerable and effective points of attack upon it. Armed with such knowledge, they devised engineering means for cutting the avenues of travel of the agent from the infected to the susceptible individual (also from animal to man) or for destroying the agent at some point during its passage through the environment.

In its contribution to control of communicable diseases, sanitary engineering drew largely upon bacteriology, later expanded to include other branches of biology as the attack was directed toward such diseases as malaria, typhus, plague, which involve in their spread, higher forms of life. As the field has grown and the objectives of sanitation have expanded, engineers in this field have had to draw to even greater degree upon biology. Today, problems in water purification, treatment and disposal of sewage and other wastes, food processing, etc., require in their solution the most highly developed integration of biology and biochemistry with the physical sciences and engineering.

The improvements in public health through sanitary engineering have been great. The filth-borne diseases and those spread by insects and animals have largely disappeared in many areas of the world and are no longer of primary concern in countries which enjoy the benefits of modern sanitation. There remain many parts of the world where the level of protection is low and the death rate from communicable diseases is still high. This is not for lack of technical "know how," however, but for reasons outside of sanitary engineering itself. There remain also many problems of sanitary engineering within the United States and similar countries which require further technical refinement and others for which more economical methods of control are needed. New problems are coming constantly to attention for which no immediate technical solutions are at hand and, therefore, require research and development. It must be remembered, too, that the objectives are not limited to the prevention of communicable diseases. The public demands a clean and decent environment and little distinction is made between specific disease hazards and simple nuisances.

Also, sanitary engineers, with other public health workers, recognize the indirect effects of poor environments upon the health and welfare of people. Conservation of water resources and the maintenance of adequate supplies of water of high physical and chemical, as well as biological, quality are essential to the welfare of a community. Certainly, the economic health of a city may be critically determined by its ability to supply adequate quantities of water of necessary quality to its industries and to dispose of their wastes in a satisfactory manner. Sanitary engineers have a responsibility to contribute their technical knowledge and skills to the restoration and proper use of the natural water supplies. Not the least important objective today in this respect is to secure and maintain water resources for recreational use.

Thus, the need exists for strengthening and expanding sanitary engineering in its traditional area of operation. In respect to the present and future problems of public health in the United States, however, it is evident that the "golden age" of communicable disease control through environmental sanitation is over. The remaining problems are those of expanding sanitary protection, maintenance and refinement of sanitary works and projects and one can no longer expect to measure the accomplishments of sanitation in terms of reduced death rates from communicable diseases.

Such progress stands as a great monument to sanitary engineering. In very large measure, these accomplishments have contributed to a remarkable change in the nature of the health hazards to which man is now subjected and which will plague him in the future. Since 1900, the U. S. death rate from infectious diseases has dropped about 90 per cent. Mortality from non-infectious diseases, however, has increased more than 50 per cent. This is a natural consequence of the survival today into the older age groups of great numbers who, in earlier years would have died from infectious diseases. In 1900, on the basis of life table data, only 75 per cent of the population would have survived to age 25 and one-half would be dead by age 57. In 1950, 95 per cent were expected to survive to age 25 and, among whites, one-half would live beyond age 70. Today, the infant mortality is accounted for principally by pre-natal disturbances and accidents of birth. Accidental deaths from poisons, automobiles and other such hazards of the environment account for the largest number of deaths in 1-5 year age groups. Fatal accidents continue to lead the mortality list up to age 25 and heart disease, cancer and vascular lesions take over in the older age groups.

The significance of these changes is great. There has been a fundamental shift in the nature of the public health problem and, in its new form, there is need for new tools and procedures and even new yardsticks for determining the relative magnitude of different parts of the total problem and also for measuring accomplishments. Clearly, the death rate in a population is no longer the most meaningful index of health status and the objectives of public health do not now emphasize a continuing reduction in mortality. A high percentage of the population survives into the adult years and a major objective today and for the future, therefore, is the prevention of illness, rather than early death, and the maintenance of long life, as free as possible from disabling illness, both physical and mental. According to one eminent public health authority, little if any truly preventive medical help can be given to the elderly, and the most promising age group with which to work is the young adults, 20 - 45 years of age. Effective preventive measures, he argues, can hopefully be applied to this group to relieve those stresses (including environmental) which bring about or speed up the progress of degenerative diseases and disabilities.

Sanitary engineers have not limited their activities to control of the biological stresses of the environment, although their greatest accomplishments have been in this area and, in the main, the body of technical knowledge upon which they depend for professional position as specialists has to do principally with such problems. Thus, the typical sanitary engineer has been trained basically in civil engineering, to which he has added competence in chemistry and biology.

A few sanitary engineers have concerned themselves with problems of the atmospheric environment and others have made notable contributions to problems of housing. City planning and zoning have interested others, even beyond the problems of water supply and waste disposal. Whipple, for example, became interested in ventilation, air conditioning and air cleanliness (including community air pollution) more than forty years ago. He played an active part in the first planning and zoning program in New York City. Winslow, although not a sanitary engineer, made notable contributions to the field of air sanitation, as well as water sanitation and, indeed, laid the foundation upon which the modern procedures of ventilation and air conditioning for human health and comfort are based. He was also one of the pioneers in industrial hygiene. Phelps, similarly, was actively interested in problems of environmental health beyond those of the traditional area of sanitary engineering. The first American school of public health, established jointly by Harvard and M.I.T. in 1910, was organized by Sedgwick, a biologist, Whipple, a sanitary engineer, and Rosenau, a physician. Included among the programs of study was one in industrial hygiene. Later, with particular recognition of the need for training engineers for this field, Professor Fair initiated the plans which resulted in the present industrial hygiene program at Harvard. Today the scope of sanitary engineering, as defined by members of the profession, includes problems of air pollution, both within industry (one important part of industrial hygiene) and in the community, protection against radioactive substances, and a host of other environmental health hazards, to which we must add accident hazards.

It is significant to this discussion of the future of sanitary engineering that Phelps, some years ago, found it necessary to propose the term "public health engineering" to connote a broader coverage than traditional sanitary engineering. One senses that he found the latter term to have taken on a restricted meaning with too much emphasis upon its purely engineering aspects and insufficient recognition of its primary responsibility to discover and solve environmental health problems which depend upon an effective integration of knowledge of man with knowledge of the environment for their solution through engineering means. He emphasized the need for the new term to cover the accomplishments of public health <u>through</u> engineering rather than to give a name to a special body of technical knowledge. Phelps' suggestion has not been generally adopted by engineers and the term is in wider use by others in public health than by engineers. In the marginal areas of sanitation, which were included under the broader term, engineers have not found any great technical challenge or the need to develop a body of engineering knowledge comparable to that involved in the areas of water supply and purification, sewage treatment and disposal. In the organization and conduct of programs of general sanitation, they became primarily administrators and, of greatest importance, they were unable to relate their accomplishments directly to the solving of measurable public health problems. The concept of "public health engineering" has thus failed on two counts: it has not developed for itself any

separate and cohesive body of technical knowledge and, in respect to its contribution to the advance of public health, it has been too diffuse and nebulous.

In such clear-cut technical areas as ventilation and air conditioning, industrial hygiene, accident prevention, and most recently, in the control of radioactivity hazards, one finds different engineering specialists at work, drawing upon considerable bodies of knowledge in physical science and technology, quite different from those employed in the traditional area of sanitary engineering, and drawing also upon branches of biology not related to bacteriology. Thus, in ventilation and air conditioning, the biological base is in physiology and psychology. Some of the important problems in industrial hygiene find their base in human biochemistry, toxicology and pathology. Radiobiology is a new science with which the engineer must become familiar, along with mastery of nuclear physics, if he is to contribute importantly to the control of this newest of environmental hazards. In the field of community air pollution, similarly, one finds a new group of specialists, dealing with another kind of health problem, as yet not well understood, through the use of such fields of physical science as meteorology and cloud physics and on the technical side, combustion engineering and chemical engineering.

These several different activities come within the definition of sanitary engineering in the sense that they have been developed to provide engineering structures for the protection and promotion of health and to make certain that other engineering works are designed and operated in such a way as not to injure public health. They are, however, distinctly different fields of specialization, each with its own separate base in physical science and technology and drawing upon its own appropriate area of biology and medicine. The different specialists use little technical knowledge in common and do not see any immediate and obvious need for joining forces under a common professional title such as sanitary engineering or even public health engineering. Secure in their own separate areas of physical science, biology and technology, with impressive collections of instruments and technics of analysis and special competence for solving particular kinds of health problems, the several specialty groups strive to maintain their separate identities.

There is considerable logic in maintaining separate fields of specialization to serve the different problem areas. This comes from the essential need for interdisciplinary teamwork in the successful solution of the problem in each area. The contribution of engineering to health protection in industry, for example, would be seriously limited without close professional association with chemistry, toxicology, physiology and industrial medicine, and this gives cohesiveness to industrial hygienists as a group, regardless of their different backgrounds. Engineers working alone would not enjoy positions of consequence in the industrial health field.

It is not enough, therefore, simply to lay claim to all of the new health problems arising out of environmental stress in support of the future growth of sanitary engineering. A common base of operation must be demonstrated which characterizes and is essential to the work of all engineers in public health if they are to function under one professional title. Clearly, this is not found in a common technology. Indeed, too much emphasis on the technical aspects tends to separate rather than to bring the different engineering groups together. A common base is found, however, in the unique objectives and responsibility, as stated at the outset—the protection and promotion of human health through engineering procedures. In the broadest sense, as suggested by Phelps, public health engineers are specialists who, by virtue of an added

knowledge of man and how he responds to environmental stress are able to utilize the technical knowledge of their underlying engineering fields, in the design and operation of engineering works, to ensure protection to human health, with an effectiveness not attained by their own professional colleagues. Other engineers may possess or can readily acquire the same technical knowledge but, without special preparation for the work, they will not possess the essential understanding of the human side of the problem.

Full appreciation of this point of difference is essential to the continuing growth of sanitary engineering, and especially so in view of the changing nature of environmental health hazards. In the earlier days of sanitation, engineering design did not depend directly upon the behavior of man but was based, rather, upon the behavior of other biological agents. Sanitary engineering had a strong base in biology but not in human physiology, psychology or medicine. The environmental stress factors of concern now and in the future are of a different type, many of which act directly upon man, and an understanding of the multi-faceted stress-strain relationship involves an intimate knowledge of man which the engineer must translate into engineering terms. He must work in close association with bioscientists—physiologists, psychologists, anthropologists, sociologists and physicians. He must develop for himself a strong position in the team, for he cannot operate effectively in an independent professional capacity.

These many new impacts of environmental stress upon man, although not as direct, perhaps, as are the relationships involved in the spread of communicable diseases, may be of greater consequence in determining the health and well-being of the people in our modern complex society. Through science and technology our capacities to use and regulate the forces of nature for the benefit of man are almost limitless. It is recognized today, however, by engineers, as well as sociologists and other students of human affairs, that when applied with only a limited view of their consequences, these capacities can bring unwanted results as well as benefits.

Indeed, many of the newer environmental hazards are the direct consequence of advances in technology and reflect an inadequacy in engineering. If society is to enjoy the benefits of technology in full measure then engineers must assume greater responsibility for the total impact of their creations upon man. They must extend their body of systematic knowledge to include man and his response to environmental stress and draw upon this knowledge, as they do the laws of physical science, in the course of analysis, design and operation of engineering works, machines and other projects. It is the peculiar role and responsibility of sanitary engineers to take the lead in this development. Viewed in such basic terms, rather than in the more restricted terms of a special technology, the continuing and increasing accomplishments of sanitary engineering are assured.

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BASIC CONSIDERATIONS IN THE MEASUREMENT OF AIR CONTAMINANTS[a]

Wesley C. L. Hemeon[1]
(Proc. Paper 1169)

ABSTRACT

Influences dominating much thinking relative to measurement of air pollution include industrial hygiene techniques, techniques that have originated as a part of Los Angeles smog research, and the traditional visual basis of smoke inspection. The distinctly limited applicability of those principles is discussed, followed by basic consideration of the nature of measurements and the background for their interpretation. The principles enunciated are illustrated by detailed discussion of the development of one particular measurement method, the filter paper black stain sampler, including several items of illustrative data.

There appears to be prevalent in the present state of development an amorphous set of attitudes on the subject of air pollution measurements --- and the attitudes seem to be dominated by three main influences. One of these is due to knowledge of the techniques of air sampling and analysis that have been applied for many years to in-plant problems by industrial hygienists concerned with the health or sensory comfort of workers. Another is due to the enormous volume of work that has been done during the past 10 years in the west by workers conducting research on the Los Angeles smog problem. There is also a dominant effect due to the age-old practice of visual inspection of air pollution sources. These three influences are ones which represent a negative aspect and we shall discuss them before looking at the inverse side of the coin.

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a. Presented at a meeting of the Sanitary Engineering Division, October 16, 1956, Pittsburgh, Pa.

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Industrial Hygiene Air Analysis

The industrial hygiene techniques are not properly applicable to outdoor air pollution measurement basically because they were designed for different objectives. Their purpose, in an in-plant study, is to obtain air concentration data that will permit predictions concerning the possibility of injury to worker health due to chronic continued exposure to a particular contaminated atmosphere and is practically never applied to the accidental lethal type of air contamination. Thus it is clear why industrial hygiene air analysis is not applicable to outdoor studies. In the first place, air pollution is not recognized, generally speaking, as a problem of chronic health hazard. And even if some day this statement should need to be modified, we have today no basis for pointing to any particular compound as hazardous to health.

When we turn our attention to the unquestioned acute air pollution episodes like the one in Donora we see again the lack of a basis for air analysis of the industrial hygiene type. It will be recalled that the purpose of industrial hygiene air analysis is essentially to provide the basis for anticipating future effects and just as it is not adapted to anticipating accidental occurrences, so in the case of actue air pollution episodes an analysis is not useful for predicting a smog condition. This would be the role of meteorology.

Los Angeles Type Measurements

The Los Angeles smog study methods frequently attract attention for their possible use in the measurement of air pollution elsewhere and this is understandable in view of the tremendous volume of scientific study that has been published on this subject. They deal with chemical methods and instruments for measurement principally of ozone or other similar oxidants, nitrogen, oxides, hydrocarbons. These substances are the primary reactants in the formation of Los Angeles smog and knowledge of their concentration and the variations therein are important to that locality. The reason for their importance there is partly due to the frequent restriction in nature's ventilation system which reduces the rate of air motion to levels undoubtedly far below those of any other large city in the world. The atmospheres of other localities have the same ingredients and sources of ingredients but because of the characteristically higher rates of ventilation and the overwhelming effect of other kinds of air pollutants, the Los Angeles effect is insignificant. (Incidentally, it seems likely that if the heating season smoke of some of our eastern and midwestern cities were to be channeled into the Los Angeles atmosphere during its critical late summer and fall period, its smog problem would be worse than anything seen there or anywhere else.)

Visual Inspection Criteria

Finally consider the influence of visual inspection practices. The prosecution of smoke control programs since the early days of such activity has rested on observations of the relative blackness of coal smoke as it issues from chimneys. Coal smoke was originally, of course, the universal air pollution problem and it was logical then to employ a check method like the Ringelmann chart based on visual methods (in spite of the obvious shortcomings of that method). With the advent of new fuels, new combustion methods

and more particularly new industrial processes, the nature of solids emissions was changed from one dominated by coal smoke to a complex array of fumes, pulverized coal ash, heavy fuel oil fumes and others. For these the Ringelmann chart is not, in general, applicable (although it has been adapted to Los Angeles to the rating of non-black fume emissions).

It can readily be shown by reference to laws of optics and of light scattering that the visual appearance of an emission frequently bears no relation to the intensity of the pertinent air pollution effect perceived at ground level in places of habitation. Visualize for illustration a hypothetical community having two separate industrial emissions, one a white metal fume of zinc oxide and the other a coarse dust resembling beach sand in particle size. The sand grain emission would be invisible at the point of discharge but gravitational deposits on the surrounding premises would be noticeable and objectionable. The contribution to dust fall from the metal fume, on the other hand, would be nil because of its small particle size and consequent low sedimentation rate. The population in this community objecting to the dust-fall nuisance would almost certainly point the finger at the visible metal fume emission as responsible for its soiling nuisance. It is easy to imagine how confused matters can become where visual criteria as applied by citizens are permitted to dominate and to dictate the nature of enforcement action. There are certainly many instances where the visual criterion does correspond to an important nuisance and serves to emphasize how important, therefore, it is that engineering measurements and engineering analysis determine the facts of air pollution.

BASIS FOR SELECTION OF APPROPRIATE METHODS

Having considered the influences that tend to confuse the question of measurements and survey methods, we may now consider how measurement methods are to be selected and the results interpreted.

Definition of Measurement

It is important to one's thinking at the outset to review the nature of measurements. Measurement comprises essentially the securing of data for purpose of comparison with some other data in a manner to permit useful conclusions. A linear measurement is a comparison with a universally recognized standard length in Washington, and cubic or other like measures similarly. A combination of two dimensions as in a measurement of concentration introduces another type of comparison best illustrated by examples.

Interpretation of Concentration Measurements

The results of a measurement of acid concentration or of oxygen concentration in streams provides a quick basis for comparison with prior research involving mortality of fish, for example. The new measurement is made for comparison with those made in the comprehensive studies and permits valid inferences to be drawn by the simple analytical results in the probable survival of fish life.

The measurement of phenol in drinking-water supply destined for

chlorination permits conclusions to be drawn concerning the palatability of the water after chlorination by making comparisons with research studies which involved not only determination of phenol concentrations but subjective observations of water taste.

Measurement of sulfur dioxide concentrations in the atmosphere can lead to conclusions as to the probable deleterious effect on certain types of vegetation, but only because researches have been conducted in the past which have included studies of plant reactions to various levels of concentration and time of exposure.

These and many others like them represent cases where concentration measurement can lead to useful conclusions because of prior research.

Where such research on the effect of some contaminant is lacking, the results of air analysis for that substance will lack full significance. If there is no background for drawing comparisons there is usually little or no point in performing the analysis in the first place.

What Substances to Measure

In point of fact there are few substances occurring commonly in the atmosphere of cities and towns for which there are any background data relating concentrations to some objective and objectionable effect. SO_2 is one of these; at certain low concentrations there may be deleterious effects on crops depending on variety, on the season and on the time of duration. But even in this case there is often no logic in applying such concentration criteria to atmospheres inside cities and towns where crops do not exist.

There are, similarly, some data on concentrations of hydrogen sulfide which may blacken exterior house paints containing lead but this phenomenon is not a commonly occurring pollution event in most communities and therefore even the analysis of this gas does not provide a very interesting basis for characterizing the air pollution levels of a community.

TIME AND LOCATION COMPARISONS

There is one other basis of comparison which has utility in air pollution measurement; that is in the examination and rating of a series of concentration measurements obtained in different circumstances. These show how concentrations vary in relation to the other factor, for example, time or location. The objective in a particular survey may be to ascertain the extent to which one region differs from another in air pollution intensity --- one neighborhood from another within one larger community or one city from another; or it may seek simply to obtain measurement data to provide basis for comparisons from hour to hour, day to day, month to month or year to year.

What kind of measurements can be logically applied to such objectives?

Establishment of Objectives

In an initial consideration of various measurement methods, it is essential to analyze one's specific objectives in clarifying detail in order to determine what type of measurement can be most logically applied to the immediate problem. Having in mind the basic function and the nature of measurements,

it soon becomes apparent for one thing that a universal license exists, granted to all scientific workers, to invent new measurement methods and units for their description if there is need for them. We availed ourselves of this license with particular objectives in mind a few years ago and a recitation of this development may serve to illustrate some of the principles which are under discussion in this paper.

Smoke Measurement Illustration

With respect to atmospheric particular matter, smoke, fumes, dust, etc., we had classified them in terms of their inertial and optical effects as fine particulates and coarse particulates, or in more common terms of everyday experience, "smoke" and "dust fall." We have discussed in other publications[1,2] the lack of logic in measurement of weight concentrations of suspended particulate matter where one is concerned mainly with optical nuisance effects. The ideas can be best summarized by pointing to an analogous situation wherein, during a drizzle of rain admixed with a heavy fog, one seeks to determine total water content per unit volume of air by aspiration of an air sample through a particulate trap and a water-vapor adsorbent. The total weight results from the mixture of relatively large rain droplets, the finely divided particles comprising the fog and also of course the invisible water vapor that is also present. The results of such a measurement could not be usefully related to any phenomenon of human interest. On the other hand, a rainfall gauge would effectively measure one significant quality of one atmospheric condition whereas an optical measurement such as light transmission or reflection (i.e., light scattering) applied to the fog constituent would effectively describe its quality that is its effect on visibility and its concentration.

The same reasoning applies to suspended particulate matter in air pollution. Measurement of dust fall carried out in much the same manner as for rainfall is a common and useful technique.[3] However, for the smoke constituent, which is analogous to the fog in the water mixture, there was not available any widely recognized measurement method suitable for the purpose, so we set out to develop one based on the following ideas.

Coarse and Fine Particulate

The fine smoke particles in atmospheric pollution are responsible for two principal nuisance effects. One of these is the optical effect causing reduced visibility and the other in the soiling of surfaces, building facades, ceilings, curtains and draperies. One could elect to devise a measurement based on the optics of light obscuration or of light scattering and this has in fact been done by several workers. For various reasons it seemed more logical to us to consider the ultimate soiling effect and to base the measurement method on that effect.

Standard Launder Test

One could expose standard pieces of fabric and after a suitable lapse of time, remove them to the laboratory, launder them in a standard detergent

solution and then measure the reduced transmission of light through the resulting turbid suspension. Results of a series of such measurements at different parts of a city or in different cities as well as by month to month over a long period of time, would provide a faithful indication of the relative concentration of this one quality of air pollution and effectively show the difference between different regions and changes with time. Similarly one could expose pieces of white paper and measure the degree of soiling by suitable optical measurements. It should be noted that either such measurement results in a concentration figure which is directly related to the nuisance effect perceived by the people who are affected. The same is true of the dust fall measurement, which describes a different quality.

Filter Paper Stain Test

We actually gave consideration to this type of measurement but eventually turned our attention to the development of a sampling apparatus and method which, while based on fundamentally the same considerations, had a number of advantages. This was the filter paper smoke sampler, details of which have been published elsewhere.(2) It consists essentially in a device for aspiration of the air sample through filter paper for a specified period of time, and subsequent measurement of the reduced light transmission through the resulting stain. Equally important was the development of a system of logical units (cohs), for describing the stain intensity in terms of optical density.

It will be noted that the first single item of data obtained by a new system of measurement could have had no significance whatever because no other data existed then with which to compare it. As data are accumulated and comparisons become possible, interest and significance can then be attached to all measurements on a relative basis.

These points are illustrated in the several figures following:

Figure 1 is a graphical description of the history of smoke concentrations in the Oakland area of Pittsburgh for the past 3-1/2 years in which each point represents the average of about 360 separate measurements, all data being based upon the filter paper stain method and results expressed in the optical density units, cohs per 1000 feet.(2)

Some hourly data are presented in Figure 2 and illustrate how significant a comparison can be between two localities a few miles apart.

In the course of this development a comparison was inadvertently made between some data obtained in Columbus, Ohio and in the Oakland section of Pittsburgh, with the remarkable result displayed in Figure 3. Parallel increases and decreases in smoke concentrations are seen to occur over a three-week period and is quite evidently due to the same atmospheric condition which resulted in approximately equal rates of ground level ventilation during that period.

Significance of Concentration Variations

Variations in the intensity of smoke concentrations are the result of two variable factors. One is the rate of generation of smoke, solid fumes and fine dust; the other, changes in the rate of natural ventilation near the ground due to meteorological factors. It is likely that the generation of fine particulate matter from innumerable sources does not vary greatly over consecutive

periods of hours, days and perhaps for considerably longer periods so that the considerable changes in concentrations in 24 hours and from day to day can be very largely ascribed to changes in the natural outdoor ventilation rate.

This is apparent in the remarkable synchronism in hourly and daily variations seen in measurements obtained simultaneously scores of miles apart. It is also borne out by data showing that concentrations of different kinds of pollutants normally occurring in the atmosphere increase and decrease at the same times. These facts demonstrate that these typical variations in the intensity of air pollution can be indicated by the measurement of almost any gaseous pollutant as well as of the fine particles in units of light-scattering potential.

SUMMARY

We have aimed, in the preceding discussion, to emphasize the following as basic factors in the design of an air pollution measurement system. On the negative side of the question the following three points have been made:

1. There is no logic in air analysis outside west coast cities for gaseous substances that are significant in Los Angeles because in other cities other types of pollution completely dominate and overshadow the Los Angeles constituents.

2. Outdoor air analysis of the industrial hygiene type lacks significance because no information exists on any air polluting substances responsible for chronic health injury, much less on significant concentrations. In the case of actue health hazards of the accidental type, air analysis serves no useful purpose because the events themselves are non-routine; in fact, highly exceptional.

3. There is practically no background describing a relationship between concentrations of any substances occurring commonly in city atmospheres and some known effect of either objective or subjective character to which air analyses can be related and permit drawing of significant conclusions. (For agricultural areas there are data of this sort on SO_2 and some on fluorides.)

The foregoing discussion rather completely relegates the role of analytical chemistry to a place of minor importance, insofar as one is concerned with routine measurements designed to characterize the air pollution intensity of a community.

On the positive side we must recognize the following principles:

1. Measurements of air pollution intensity, e.g., concentrations, can be significant and therefore useful, only if one of the following two criteria apply:

a) There are in existence background data resulting from prior research establishing a basis from which broader conclusions can be drawn concerning the effects of the particular pollutant being measured. There are practically no such data that are broadly applicable to towns and cities generally. Or:

b) The measurement objective is simply to establish a body of data that permit a comparison of air pollution intensity in different regions or in the

same locality to show variation in intensity with hour of the day, day to day, month to month or year to year.

2. Where comparison of air pollution intensity is to be the basis for interpretation, the measurement of any normally occurring baseous pollutant or of the light scattering element of particulate matter will serve equally well as an index of relative pollution because of the overwhelming influence of natural ventilation at ground level.

This has been an exposition of principles applicable to surveys of a region for the purpose of defining its air pollution characteristics. Measurements which are a part of research to establish the significant sources or to explore various effects require broader treatment.

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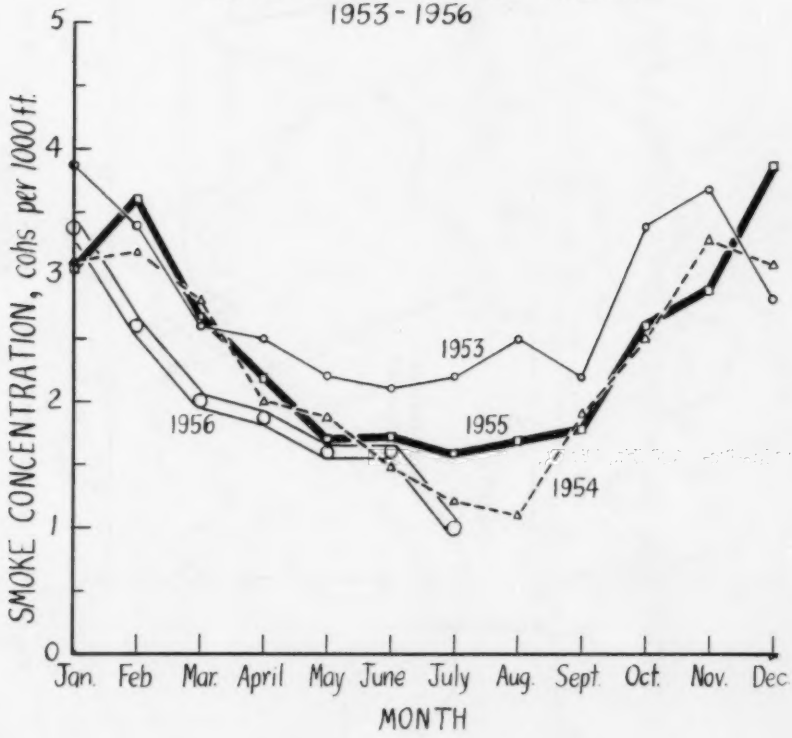
3. Sensenbaugh, J. D. and Hemeon, W. C. L. "Variables in Monthly Dust Fall Measurements." Am. Soc. Testing Materials Proceedings 1953, 53:1160.

Figure 1
SMOKE CONCENTRATIONS (MONTHLY AVE.)
FOR OAKLAND SECTION OF PITTSBURGH
1953 - 1956



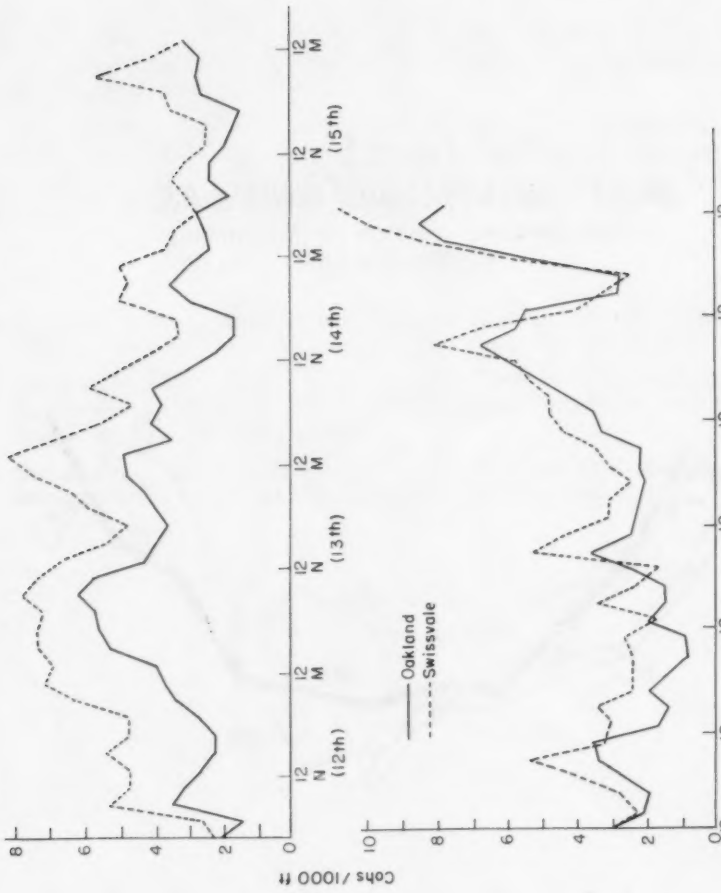


Fig. 2. RELATIVE CONCENTRATION OF SMOKE IN TWO REGIONS OF PITTSBURGH, 4 MILES APART

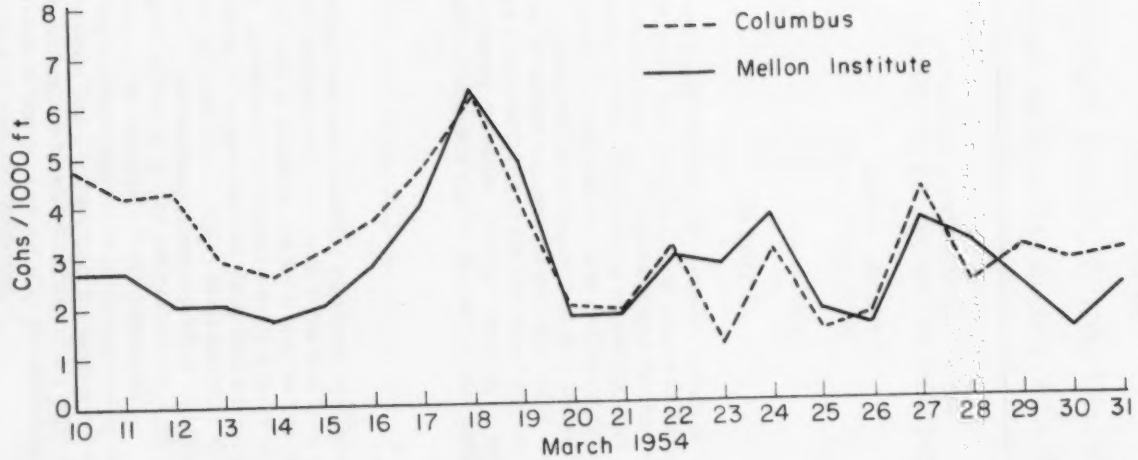


Fig 3. RELATIVE SMOKE CONCENTRATIONS IN COLUMBUS, OHIO AND PITTSBURGH, PENNA. MARCH 10-31, 1954

Journal of the
SANITARY ENGINEERING DIVISION
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THE RELATIONSHIP BETWEEN CONSULTING ENGINEERS AND INDUSTRY

David H. Miller*
(Proc. Paper 1170)

ABSTRACT

A salesman-customer relationship obviously exists between the consulting engineer and industry. The relationship is tempered however, by the constraints of professionalism and the avoidance of "hucksterism." Mutual trust leads to mutual profit. Engineering consulting work encompasses the specialist, the integrated engineering firm and the engineering contractor. A related service is provided by the builders of specialized equipment.

Industry's use of outside engineering services takes many forms depending upon both the characteristics of the consultant and the client. Through enlightened engineering services, industry receives an essential assist in meeting the requirements of a highly competitive and swiftly changing economy.

The relationship between consulting engineers and industry is a very nontechnical subject, and one which is close to the hearts of all consulting engineers as well as most of industry. While it may be true that in civil engineering circles government is proportionately a much larger source of consulting business, it is nevertheless likely that industry will generate more demand for your services than is likely to be satisfied in the foreseeable future. Much of my presentation is necessarily a reflection of the attitude on industry's side of the fence. It will not be difficult, I am sure, for this sort of audience to supply the reactions of the consultant.

The consulting engineer aspires to professionalism, but like all other free enterprisers he finds that a shingle over the door is not enough—he has a service to sell, and unless he enjoys an extremely wide reputation, he must make others aware of that service and also its availability. In short, he must get his foot in the door—be part salesman.

Note: Discussion open until July 1, 1957. Paper 1170 is part of the copyrighted Journal of the Sanitary Engineering Division of the American Society of Civil Engineers, Vol. 83, No. SA 1, February, 1957.

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There are many ways in which industry is approached by the multitude with something to sell. First, it is possible to trade upon the friendship of the owners and managers of a business. When this is done, it can be difficult to win the complete confidence of the staff members who represent management in engineering matters. Excessive reliance upon this friendship has at times, diluted the initiative and the responsiveness of the consultant to the requirements of the problems at hand. Second, it is possible to approach at the vice-presidential, chief engineer or purchasing agent level where the details of ability and performance will often receive more realistic appraisal. Lastly, it is possible to sell products and services through a detailed demonstration of reliability at the plant or project engineer level. I am sure that it must be a source of satisfaction for any consultant to discover that his client's engineering staff has become his best advertiser. The consultant should be successful indeed who can make not one of these approaches, but all three.

An exact definition of the kind and quality of service offered by the consultant should be clearly understood by both sides. After all, the very concept of the consultant in any profession is based upon mutual trust. Consequently, it is prudent to avoid overselling. We have all seen cases where so-called engineering services were offered by those who merely capitalize on a salesman's line and a desperate shortage of experienced technical help, with the result that engineering becomes costly, time consuming, and generally inferior. The consultant must also be more than the merchant of information—no thinking client enjoys paying for other people's warmed-over ideas. Furthermore, nothing is more disconcerting to me than to find my company's development being peddled to all and sundry as original engineering.

Consultants typically tend to be specialists in fields such as product development, research, electrical, mechanical or sanitary engineering—the list is almost without end. It should be only fair for the consulting specialist to give his client a realistic appraisal of the scope of his ability, so that there should be little doubt as to the need for additional assistance when the problem leads into other fields. There has been an increasing tendency toward the formation of larger firms of consultants capable of handling within their own staff the several specialties required by most modern industrial projects. This trend toward integration leads to the case of the contracting-engineer and the engineering-contractor—a development born of expediency in the effort to attract an ever-increasing amount of business. In many cases this combination appears quite attractive to the industrialist seeking to place responsibility in as few hands as possible, but it is important that in choosing, the mere specialist not be confused with the truly integrated engineering firm.

Since much of industry regards him also as a consultant, the builder of specialized machinery deserves passing mention here. Much of his approach is empirical: his technical prowess gained through long years of grueling days and nights trouble shooting and improving the performance of his product. Working closely with the operator, he has extracted ever-greater production from old machines and has displayed a great deal of wizardry in the design of new machines. There is of course an element of danger in too much reliance on this approach to engineering. The machinery builder is frequently a large industrialist himself, having a large investment in the status quo. He can become ultra-conservative and unwittingly develop a reluctance to take a new approach to an old problem. We are all aware of the great change that has come over the railroad industry in the past 20

years; namely, the substitution of diesel electric power for steam power. The builders of steam locomotives were not the pioneers in the development of this new equipment which has been so important to the economics of our transportation system.

If the consultant is in business at all, he is there to satisfy a need, and I am sure any group of consultants can recollect a great many instances where the client's total need was not recognized until embarrassment and financial loss were the result. I need not recite the stories of the buildings that settled, of the chemical processes that didn't work or of the machines that were down for maintenance longer than they operated. All these stories have one moral in common: industry needs more and better engineering which frequently means more and better consultants.

Small or highly-specialized enterprises need a general, almost personal, form of engineering service such as property survey, foundation and building design, electrical, mechanical and heat-process engineering required for a small foundry or glass plant. The medium-sized company may be well-staffed with respect to the technical aspects of its production machinery and methods, but may have a great need for advice and assistance with unusual non-repititive problems. The larger, more nearly integrated industrial empire can be or often fancies that it is self-sufficient in engineering matters. In this case, the principal requirement for consulting service results from large expansions demanding technical personnel in even far greater numbers. Responsible industrial companies will usually do everything possible to avoid repeated expansion and contraction of their technical departments in response to temporary fluctuations in work load.

New and highly-specialized problems will also send the industrial firm to the consultant's door—witness the rise of air and stream pollution problems in the Pittsburgh district resulting from recent legislation. Emergency situations such as last year's floods in New England undoubtedly give rise to a large amount of engineering activity of a rather unusual nature. In the Southwest, gradual changes in the water supply situation have also forced industry, with the help of the engineer, to seek new answers to a steadily increasing problem. Intermittent local assistance may be required by small or semi-autonomous outposts of industrial empire.

Regardless of size or specialization, all industry can be said to have certain needs in common which the able consultant can satisfy. First, industry must avoid the deadening influence of ultra-conservatism: continued growth requires early recognition of new materials and methods and markets. The recent development by the engineer of pre-stressed and post-stressed reinforced concrete designs, and his rapid exploitation of pre-casting techniques for concrete have already made a significant contribution in the reduction of investment costs. Conservatism may also appear as a form of organizational tyranny wherein the key members cannot or will not recognize valuable suggestions from within. The consultant contributes a very real service to his client if he only confirms the value of suggestions and ideas that were really home grown.

In seeking advice, industry needs to be understood. It will not prosper unless the fundamentals are recognized and the superficial approach avoided, or as the doctor would say, treat the disease, not the symptom. This, of course, is much easier to say than to do, as it is not uncommon for any organization to fail to recognize its own problems. The consultant with his

different perspective and fresh approach can often see the forest more clearly for not being so close to the trees.

A compelling need for fast action stands high on the list of those things that industry needs from its consultants. Having made the fateful decision to spend millions on another risk with the free enterprise system, owners and managers are understandably anxious for rapid realization of their plans. Interest payments on a large debt may have already begun and of course, the returns do not come in during the months the engineer is making up his mind. The industrialist may be relying heavily upon a market condition of doubtful duration. In nearly all cases, prompt and decisive performance can represent savings of millions of dollars to the owners.

Industry often has a need for independent research, but while engineers are at times involved, this is largely the field of the scientist and does not warrant further discussion here.

In more concrete terms, industry's needs usually boil down to designs, plans and specifications for projects already developed in outline form. This activity may be regarded by some as pedestrian, but herein lies a vast area of complex engineering problems ranging from linear programming to development of better electronic controls—from the physics and chemistry of phenol wastes to the aerodynamics of tall stacks. In translating the industrialist's ideas into a working synthesis of concrete and steel, the engineer is making ever-increasing contributions to the material welfare of our society. Our capitalistic system has created a mounting demand for products of all kinds. The scientist and the inventor are years ahead of practical application of their new materials and methods. Industry, faced with the need for innovations, yet at the same time being mindful of the security of its investors, has a crying need for the very best advice on engineering matters.

Journal of the
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Proceedings of the American Society of Civil Engineers

EFFECTS OF STORAGE IMPOUNDMENTS ON WATER QUALITY[a]

Milo A. Churchill,[1] A.M. ASCE
(Proc. Paper 1171)

SYNOPSIS

When water in a free-flowing stream is impounded in a large storage reservoir, changes in the physical, bacteriological, sanitary-chemical, and mineral quality of the water are produced. While most of the changes result in a generally improved water quality, certain specific qualities and certain downstream water uses may be adversely affected. This paper presents and summarizes a wide variety of observations made on reservoir waters in the Tennessee Valley during the past 20 years. The facts obtained and the general principles deduced therefrom should be helpful in forecasting the changes in water quality that are likely to occur in any proposed reservoir.

INTRODUCTION

Water, as an essential national resource, is currently receiving more study in southeastern United States than at any previous time in the history of this country. Every state in the Southeast is re-examining its water rights laws to determine if changes are desirable. People in general are beginning to realize the total supply of water is limited. It does not grow as the need for more water grows. This realization is followed immediately by the natural impulse of every individual to take steps to get at least his share of the available supply. Many conflicts in water use now exist, and quite obviously more conflicts will continue to develop. A relatively new and growing use of water in this area, spray irrigation of field crops, has already produced some conflicts with other uses and potentially can produce many more. This use is largely truly consumptive through evapo-transpiration losses

Note: Discussion open until July 1, 1957. Paper 1171 is part of the copyrighted Journal of the Sanitary Engineering Division of the American Society of Civil Engineers, Vol. 83, No. SA 1, February, 1957.

a. Presented at the National Convention of the ASCE, June 4-8, 1956, Knoxville, Tenn.

1. Chief, Stream Pollution Control Section, Div. of Health and Safety, Tennesee Valley Authority, Chattanooga, Tenn.

whereas most industrial and municipal uses pass the water through various processes and conduits before returning most of it, polluted to some degree, to the water channel.

One obvious means of stretching the available supply of water throughout the world is to prevent its wastage during periods of high runoff by storing it in reservoirs. While the storage idea is far from new, the idea is certain to have many new advocates in the immediate future. No crystal ball is needed to predict the trend toward conservation of water must be accelerated.

Since storage impoundments will inevitably become more and more numerous, and will be called upon to serve more and more uses and users, the quality of the water stored in, and released from, the impoundages will be under strict scrutiny to determine if it is suitable for the varied intended uses. Intelligent planning of water resources conservation and development requires that the advantages and disadvantages of storage impoundments be fully understood as regards water quality as well as water quantity.

Fortunately, impoundments result in many improvements in water quality so far as most uses are concerned. Some of the changes are detrimental, however, for some uses. In other words, reservoirs produce changes in stored water that are both good and bad, and the net effect is not the same for all users.

This paper presents and discusses some changes in the physical, bacteriological, sanitary-chemical and mineral quality of impounded waters in the Tennessee Valley that have been observed over a period of about 20 years. The observed data have been obtained through the years in connection with various studies and investigations that have been made for a wide variety of purposes. The data presented herein have been selected to illustrate typical effects of tributary impoundments. Some unusual effects are also included. An attempt is made to draw conclusions and state certain fundamental principles that are believed to be generally applicable for impounded waters.

A section is included on reaeration in downstream river channels of water released from the lower levels of storage projects.

A map of the eastern half of the Tennessee Valley is shown as Figure 1. River profiles of most of the major tributaries in the eastern half of the Valley are shown as Figure 2. Reservoir volumes, areas, depths, etc., for the projects discussed herein, are listed in Table 1.

Operation of Storage Projects in TVA System

In the TVA system, the reservoirs are operated primarily for navigation and flood control and are used for the production of power so far as consistent with such primary purposes. The storage reservoirs are operated on an annual cycle. They are drawn down during late summer, fall, and early winter to reach a pre-determined minimum flood-control level by January 1. The pools are allowed to fill slowly after that date. As the probability of heavy, wide-spread, flood-producing, rains diminishes with advancing spring, the pools are permitted to gradually fill to their maximum levels by early summer.

Since the reservoirs are operated primarily to control floods, the storage projects reduce the magnitude of high stream flows and raise the general level of low flows. Although the general level of low flows is raised, the usual practice is to reduce releases over weekends, and during other periods

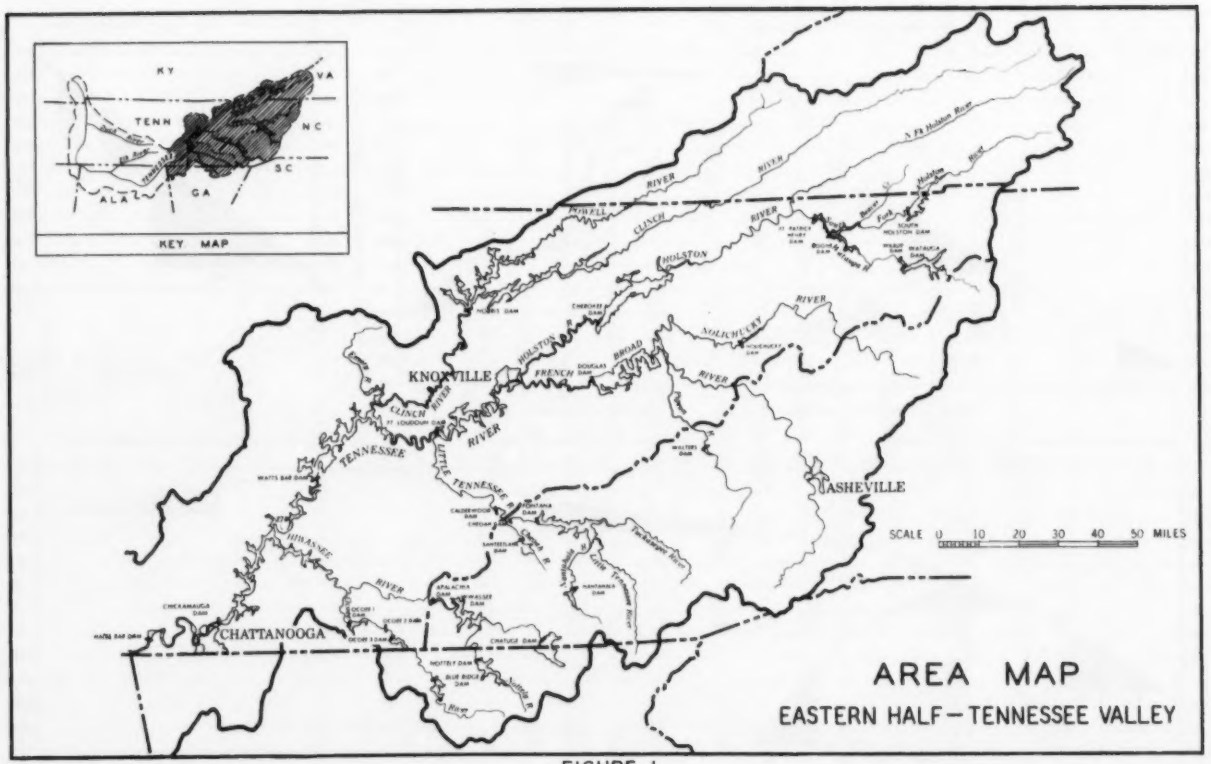
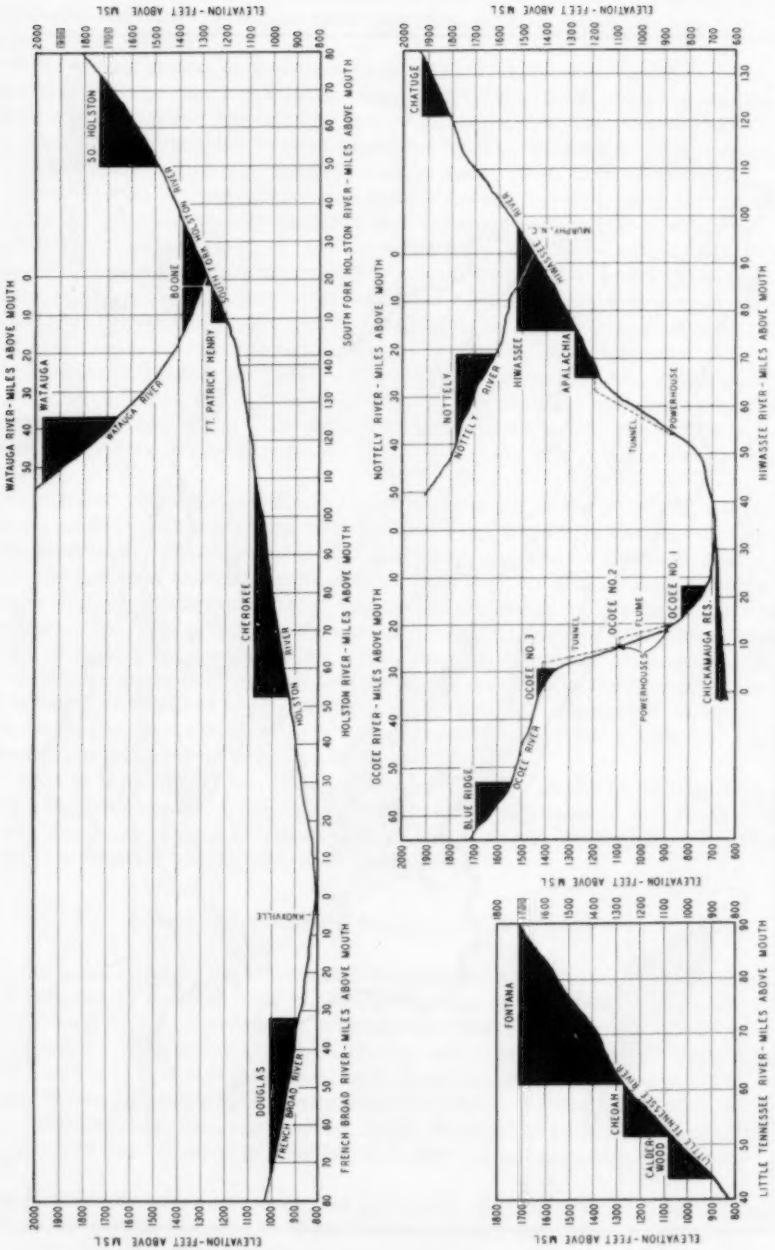

KY
VA
TENN
NC
SC
ALA
GA
KEY MAP
KNOXVILLE
CHATTANOOGA
ASHEVILLE
CLINCH RIVER
HOLSTON
FRENCH BROAD
NOLICHUCKY
TENNESSEE
LITTLE TENNESSEE
HIWASSEE
SCALE 0 10 20 30 40 50 MILES
AREA MAP
EASTERN HALF – TENNESSEE VALLEY

FIGURE 1



PROFILES - MAJOR TRIBUTARIES - TENNESSEE RIVER

FIGURE 2

Table 1

PERTINENT DATA ON SELECTED IMPOUNDMENTS

Reservoir	River	Date of Closure	Full pool			
			Volume Acre-feet	Area Acres	Length Miles	Depth at Dam Feet (approx.)
Cherokee	Holston	12-5-41	1,565,400	31,100	59	150
Douglas	French Broad	2-19-43	1,514,100	31,600	43	150
Fontana	Little Tennessee	11-7-44	1,444,300	10,670	29	440
South Holston	So. Fk. Holston	11-20-50	744,000	8,750	24	250
Watauga	Watauga	12-1-48	678,800	7,200	17	330
Norris	Clinch	3-4-36	2,567,000	40,200	77	210
Hiwassee	Hiwassee	2-8-40	438,000	6,280	22	250
Apalachia	Hiwassee	2-14-43	58,700	1,123	10	110
Parksville	Ocoee	12-15-11	91,300	1,900	7	120
Boone	So. Fk. Holston	12-16-52	196,700	4,520	17	120
Ft. Patrick Henry	So. Fk. Holston	10-27-53	27,100	893	10	80
Cheoah	Little Tennessee	12-8-18	35,030	595	10	190
Calderwood	Little Tennessee	4-15-30	41,160	536	8	190

of off-peak power loads, to only that required for downstream uses by municipalities and industries. Should no such requirements exist, the flow is usually cut off completely on weekends in order to conserve water that can be used to more advantage during peak-power demands.

To illustrate the marked alteration of stream flows resulting from the construction and operation of a storage project, 9 years of flow records on the Holston River before Cherokee Dam was built, are shown in Figure 3 together with 9 years of record after closure of the dam.

Physical Effects on Water Quality

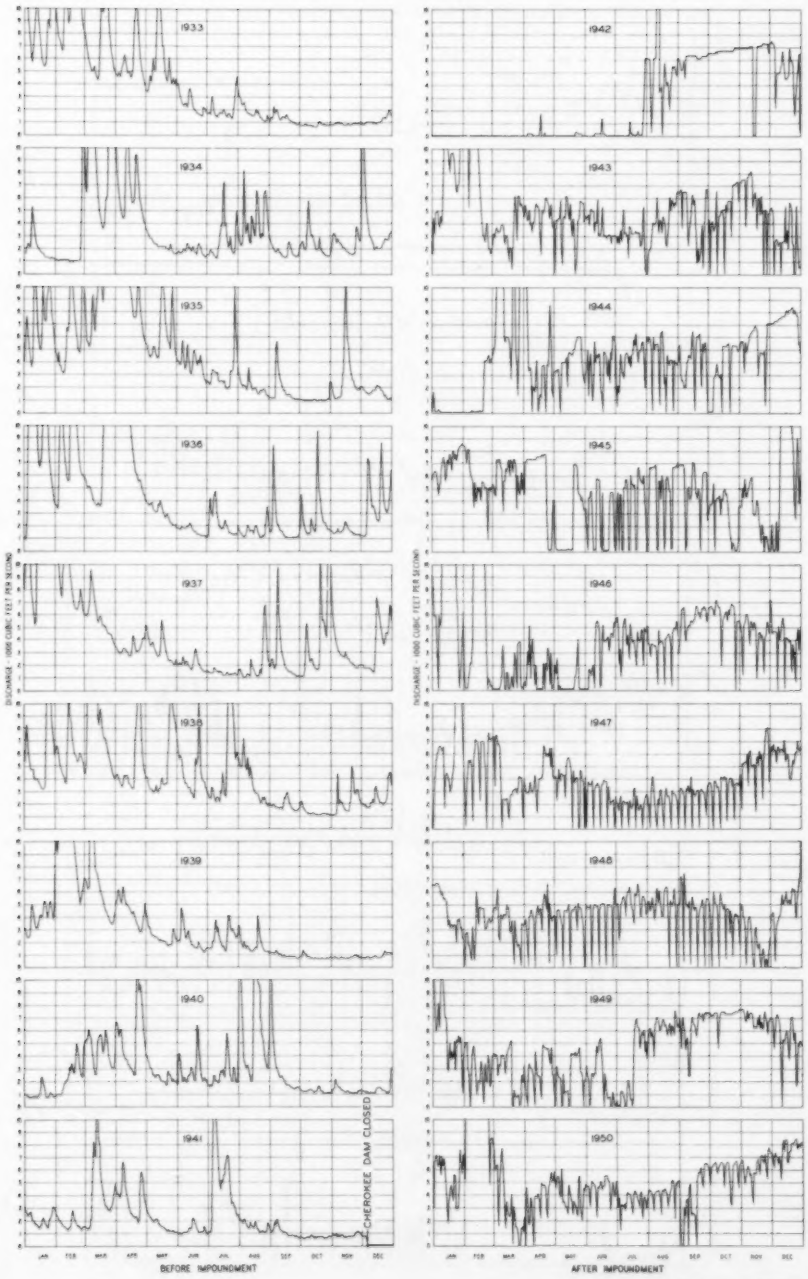
Temperature

One of the outstanding physical changes in water quality produced by a storage impoundment is the lowering of summer water temperatures below the dam. This of course assumes the power intakes at the dam are deep in the pool as is the case for all TVA storage impoundments.

A striking example of the major change in summer water temperatures produced below a deep impoundment is that shown by Figure 4 for Watauga River below Watauga Reservoir. The dam was closed on December 1, 1948. The first major release was made late in August of the following year, 1949. The top graph in Figure 4 shows water temperatures as observed by the North American Rayon Corporation at Elizabethton, Tennessee, some 12 river miles downstream from Watauga Dam during the year 1949. Normal water temperatures for local surface runoff below the dam are shown for the first eight months of the year. As the releases from the dam were started late in August, water temperatures at Elizabethton immediately dropped some 13 or 14 degrees Centigrade. During the summer of 1950 water temperatures averaged about 15°C and did not exceed 20°C. During 1951 a period of low releases from Watauga Reservoir during late summer allowed water temperatures to rise to nearly normal for local runoff. In the summers of 1952 and 1953 water temperatures at Elizabethton exceeded 20°C only rarely.

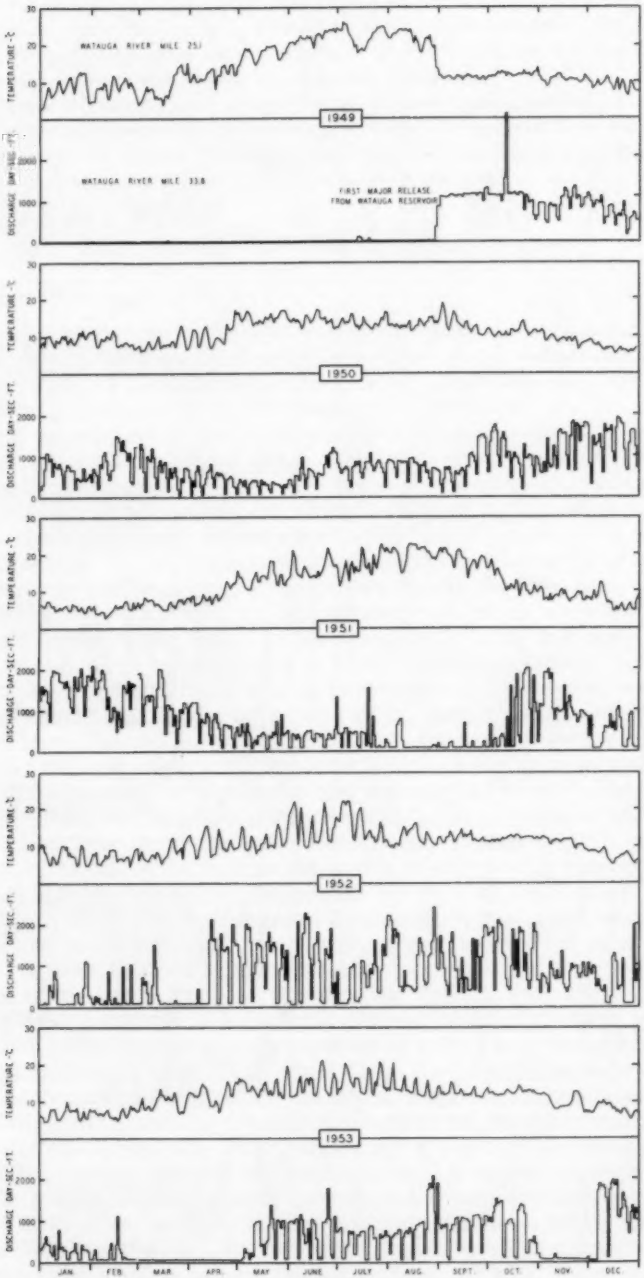
Weekly observations since 1950 of temperatures of releases right at Watauga Dam have shown the water there rarely to exceed 12°C., and then only late in the fall of the year as the supply of still colder water becomes exhausted from summer draft through the low-level power intakes.

For those unfamiliar with thermal stratification in storage reservoirs, the observations of Figure 5 for Cherokee Reservoir in 1945 will be of interest. These data were obtained by the Hydraulic Data Branch of TVA under the direction of Mr. A. S. Fry. As shown by the March 1 data, the pool at that time contained water all in the narrow range of 8° to 11°C. Very little thermal stratification existed since temperatures were nearly uniform from reservoir surface to bottom. By April 3, the warming inflows and the direct heating of the pooled water by the sun and atmosphere had produced considerable thermal stratification. By June 6 a definite thermoclime was established near elevation 1020. Since stratification, beginning in March or April, stops the vertical circulation that exists all winter in storage pools at these latitudes, draft from the low-level power intakes removes cold water from near the level of the intakes. As the supply of cold water at the intake level is exhausted from the pool, warmer water from above sinks down to occupy the vacated space and is in turn discharged from the pool. By this process the discharged water gradually warms up as summer and fall progress. For



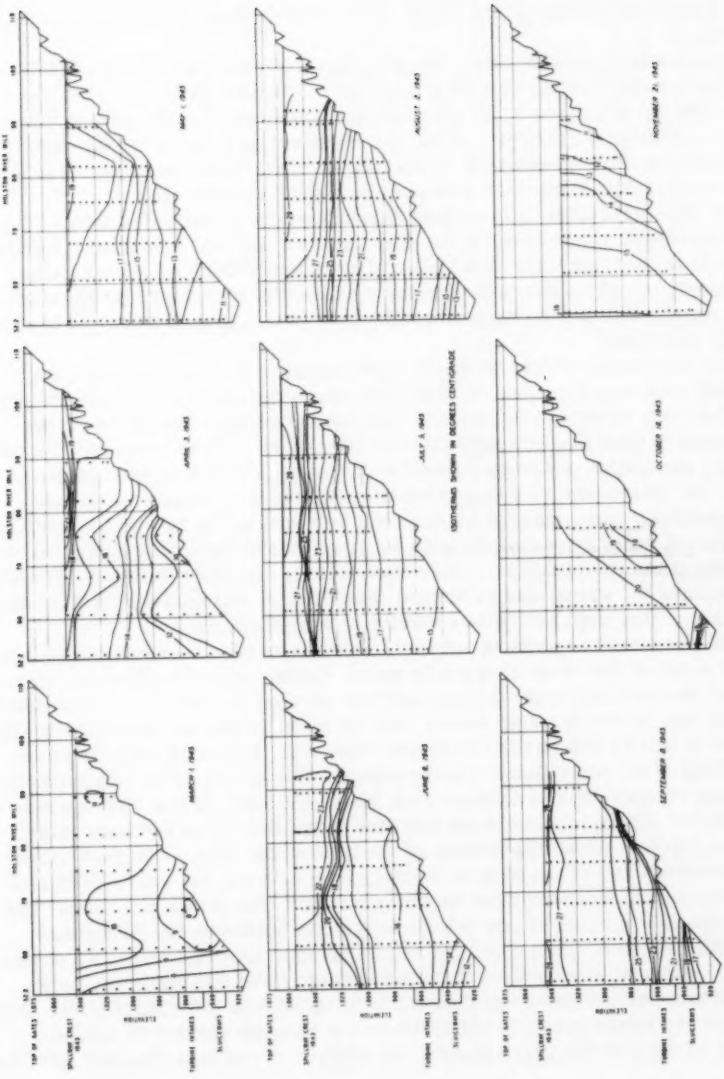
EFFECT OF IMPOUNDMENT ON DISCHARGE
HOLSTON RIVER AT CHEROKEE DAM-MILE 52.2

FIGURE 3



WATER TEMPERATURES BELOW WATAUGA RESERVOIR

FIGURE 4



THERMAL STRATIFICATION CHEROKEE RESERVOIR MARCH-NOVEMBER 1945

FIGURE 5

Cherokee Reservoir in 1945 this gradual warming is illustrated by the top graph of Figure 8. Early in April the discharged water had a temperature of 12°C. The temperature rose steadily as the supply of cold water was gradually exhausted, and by the middle of September the temperature of the discharged water was up to 25°C. An inspection of the temperature profiles of Figure 5 indicates water in the range of 21°-24° C to be at the intake level on September 8.

It is possible to predict water temperatures of releases months ahead during the summer by (1) obtaining a reservoir temperature "profile" such as one of those of Figure 5, (2) estimating the volume of releases for succeeding months and, (3) by use of an elevation-volume curve for the pool compute succeeding increments of cold water draft from the level of the intake upwards into the warmer water of the higher elevations.

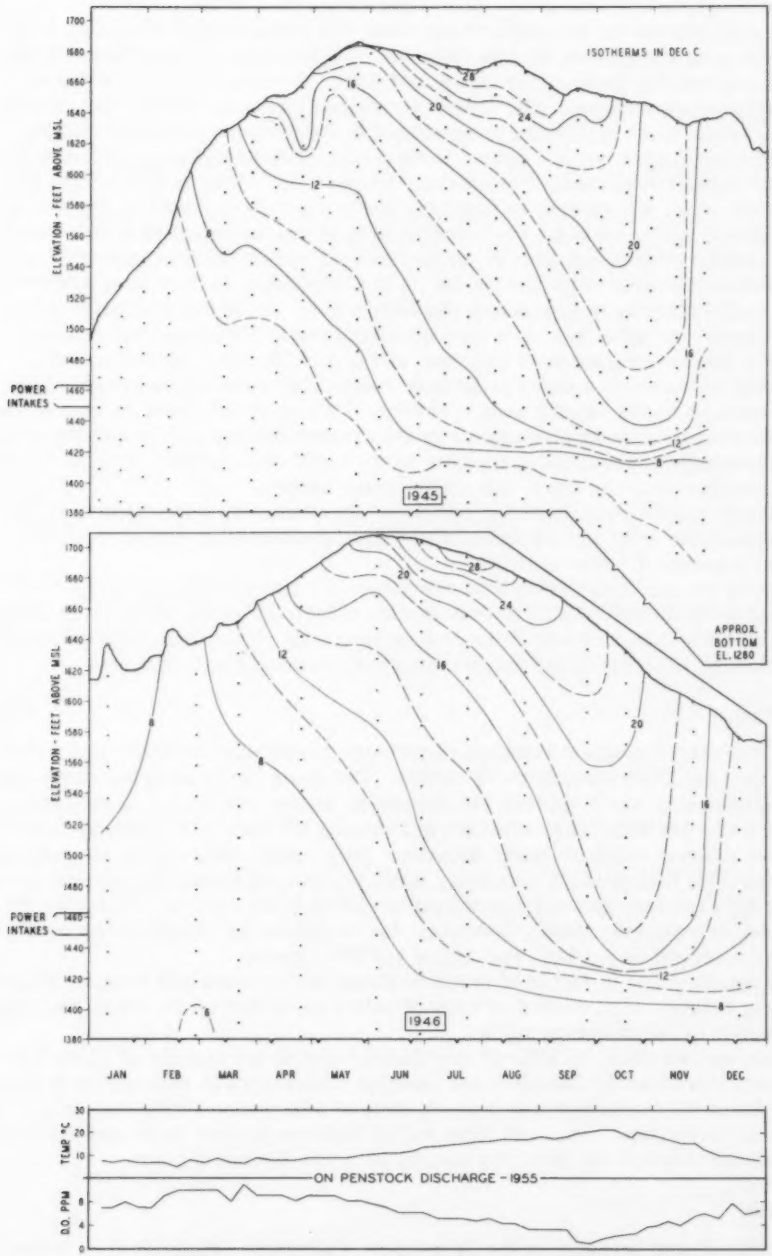
From this discussion it is evident that the extent to which the temperature of the discharged water rises in the late summer and fall is a direct function of the rate of draft on the available supply. A heavy draft on a relatively small supply of cold water will obviously exhaust it rather promptly, whereas a large supply with a light rate of draft will supply water of winter temperatures all year long.

Cooler air temperatures in the fall (beginning in September, 1945, for Cherokee) result in a cooling of river inflows to the pool faster than the great mass of pooled water can be cooled. As a result of this, the inflow to the pool ceases to flow into the upper levels and begins to flow down the old river bed under the pooled water as a density current.[1] Finally by the middle of October the entire pool is being short-circuited by the density underflow. Such underflows may continue for a month or more in the fall until such time as the pooled waters are cooled down by progressive vertical circulation to the temperature of the inflow. After that occurs, complete vertical circulation continues all winter due to diurnal temperature changes and to wind action on water that then has little capacity to resist mixing.

The temperature aspects of reservoirs are treated rather fully here inasmuch as most of the other changes in water quality are controlled to a great extent by the mechanics of storage and flow through the pool. An understanding of the way in which water moves into the pool, mixes or stratifies in the pool, and is finally discharged from the reservoir, is fundamental to an understanding of all other water quality changes that result from impoundment.

Fontana Reservoir, the deepest pool (about 440 feet) in the TVA system, has its power intake located some 250 feet below the top of spillway gates, and some 190 feet above the bottom of the pool at the dam. Figure 6 shows water temperatures at the dam at monthly intervals for the years 1945 and 1946. These data were supplied by the Hydraulic Data Branch of TVA. The upper solid line on each of the two major graphs indicates the filling and drawn-down cycle of this particular multi-purpose impoundment. As spring advances, water at say 10°C is to be found deeper and deeper in the pool since warmer inflows move into the surface strata and the colder water below (but above the intake level) is being drawn out through the power intakes. Note that in each of the years shown, the surface of the lake reached 28°C for

1. Fry, A. S., Churchill, M. A., and Elder, R. A., "Significant Effects of Density Currents in TVA's Integrated Reservoir and River System," Proceedings Minnesota International Hydraulics Convention, IAHR and ASCE, September 1953.



THERMAL STRATIFICATION IN FONTANA RESERVOIR AT DAM
SHOWING EFFECT OF LOW-LEVEL POWER INTAKES

FIGURE 6

a few weeks in mid-summer. After that the surface of the pool cooled off gradually but the temperature of the water being discharged continued to increase until the middle, or late October. By that time, cooling from the surface reached the depth of the intake and thereafter temperatures of the discharged water dropped. The effect of the deep intake in delaying the time of occurrence of the maximum temperature in the outflow is clearly evident.

Of special interest at Fontana is the nearly-200-feet-deep pocket of cold water below the intakes. For most of the year, the water in this pocket is trapped by its winter density and remains in the bottom levels of the pool perfectly still and unmoved. For a few months in the coldest part of the winter, vertical circulation apparently exists from reservoir surface to bottom.

Parksville Reservoir (Ocoee No. 1) is a relatively shallow pool devoted to the single purpose of generating electric power. As shown by Figure 7, the pool level fluctuates but little throughout the year. Although Parksville is only a little over a hundred feet deep at the dam, thermal stratification is limited as shown to a depth of 50 to 60 feet. This situation is produced by the location of the intakes high in the dam. Water in the lower 50 feet or so of the pool is trapped all summer by its greater density and so maintains its winter temperature from one winter to the next. Water flows through the pool all summer over the top of the colder water below.

Many more examples of the effects of reservoirs on water temperatures are available and some of them will be discussed later in connection with other aspects of water quality.

Deep storage reservoirs that release cold water all summer are of tremendous economic benefit to downstream industrial plants using river water for steam condensing and other cooling purposes. This very tangible benefit of storage reservoirs has not yet received the attention it deserves

Turbidity

The effectiveness of storage reservoirs in reducing turbidity is so obvious that but little discussion is needed. The pools serve as tremendous settling basins in which most of the suspended matter settles out of suspension. The pools are especially effective in reducing the turbidity resulting from intense summer rains of short duration. Only heavy winter rains of protracted duration that produce relatively large volumes of runoff (in relation to the storage capacity) produce significant turbidity in the outflow. So far as the writer is aware no density underflow due to suspended sediment has ever been observed to pass through any of the TVA pools.

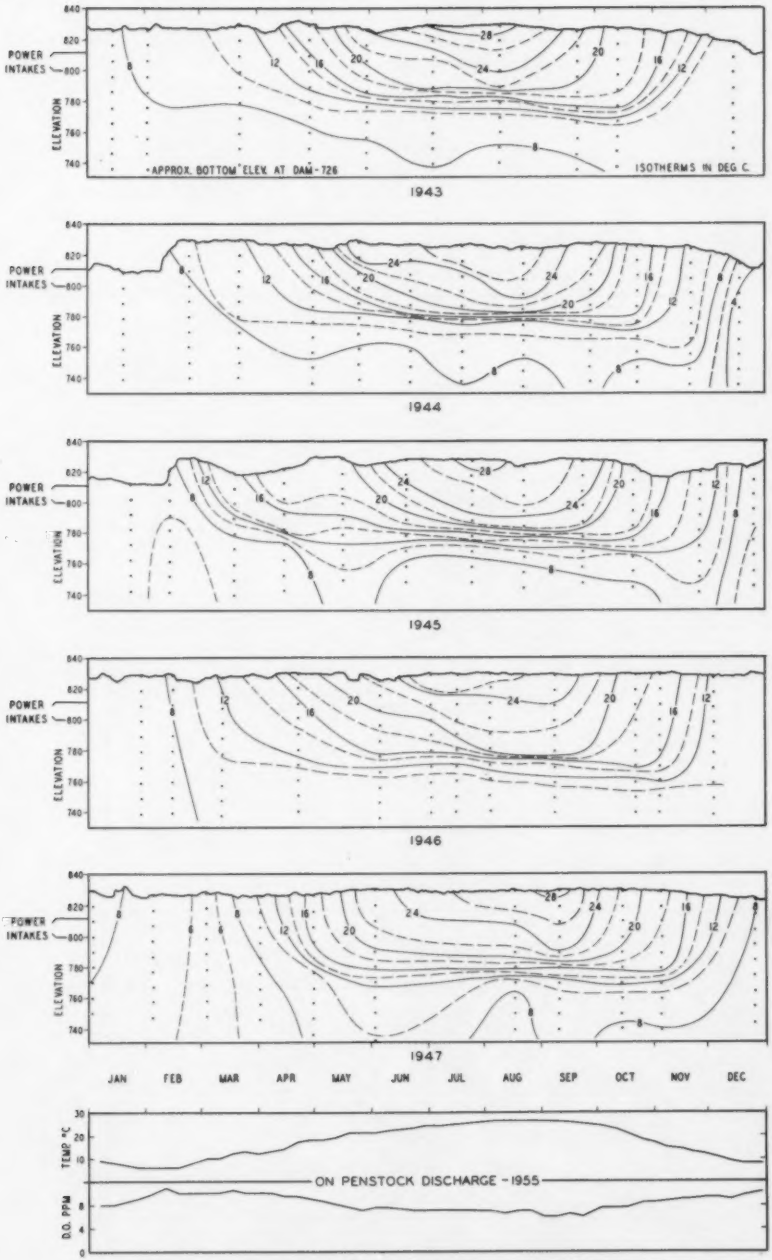
Figures 8 and 9, for inflows and outflows to Cherokee and Douglas Reservoirs, respectively, show how very effective these two pools are in reducing turbidity in the inflowing water.

An earlier study by Kittrell and Quinn,[1] one of the aspects of which was the effectiveness of Cherokee and Douglas Reservoirs in reducing turbidity at the Knoxville municipal water plant, showed a 61 percent reduction in average annual turbidities. No doubt local inflow between the two dams and Knoxville produced much of the turbidity measured at the Knoxville plant.

Color

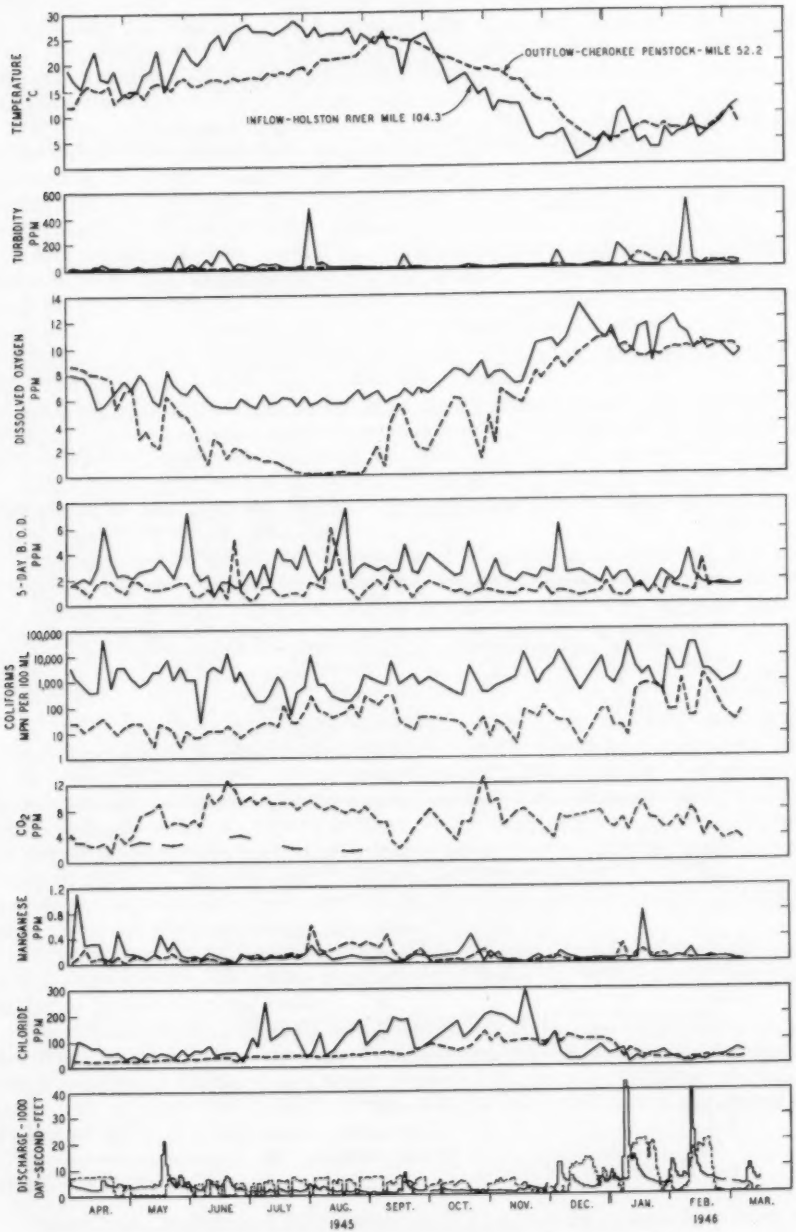
Unpolluted streams in the Tennessee Valley are relatively free from color

1. Kittrell, F. W., and Quinn, J. J., "Multi-Purpose Reservoirs Aid Downstream Water Supply." Engineering News Record, May 26, 1949.



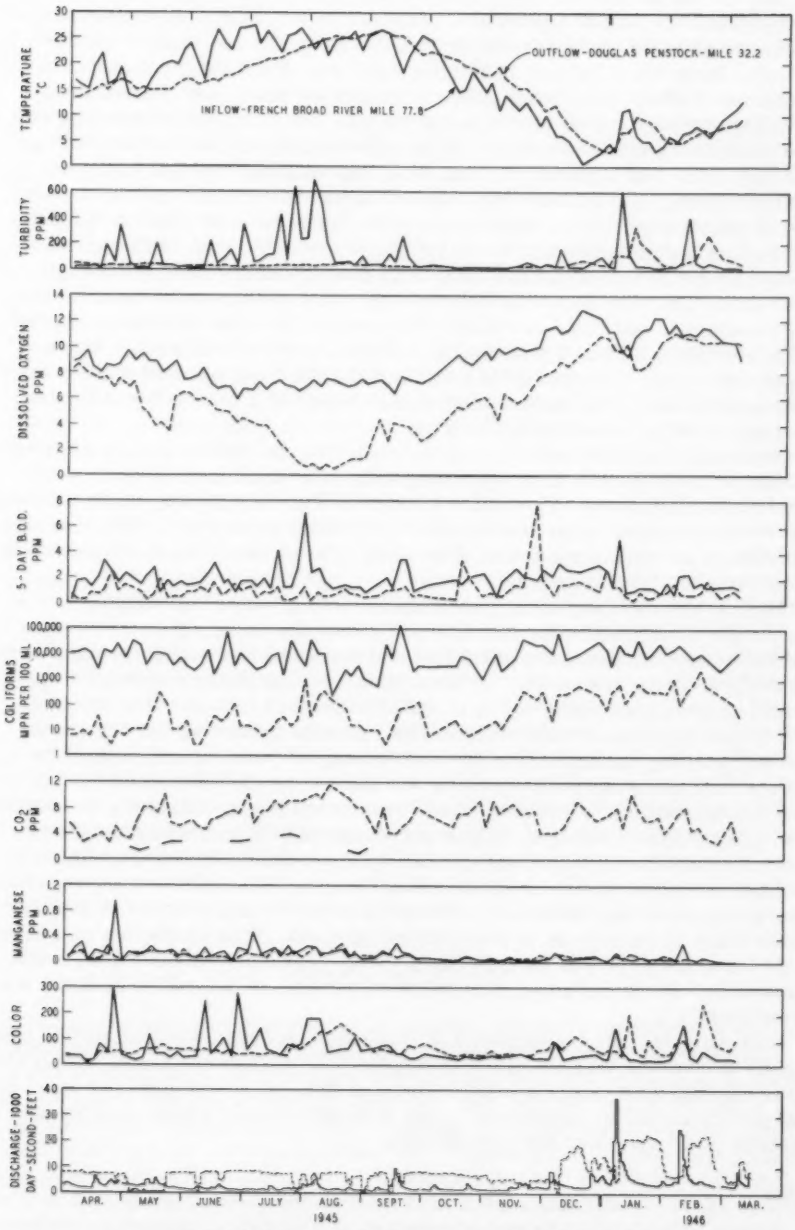
THERMAL STRATIFICATION IN PARKSVILLE RESERVOIR AT DAM
SHOWING EFFECT OF HIGH-LEVEL POWER INTAKES

FIGURE 7



EFFECTS OF CHEROKEE RESERVOIR ON WATER QUALITY

FIGURE 8



EFFECTS OF DOUGLAS RESERVOIR ON WATER QUALITY

FIGURE 9

per se. In fact any stream in the Valley having sufficient color (as distinguished from the muddy appearance produced by soil particles in suspension) to be noticed by the casual observer is practically certain to have acquired the color from some form of industrial pollution. Pulp and paper mills in the Tennessee Valley color many miles of natural streams, and the waters of two major impoundments (Fontana and Douglas), to an objectionable degree.

A fairly comprehensive study[1] of the effectiveness of an impoundment in reducing color was made on Fontana Reservoir during 1948 and 1949.

The investigation showed that in free-flowing streams the only means of natural purification that is effective in reducing paper mill color is dilution. The lignins and tannates present in the waste are relatively unaffected in a stream by the biological action that would greatly reduce most types of organic pollution. The study showed, however, that storage in Fontana Reservoir produced a reduction of roughly fifty percent in color concentration over and above the effects of dilution. The reasons for this reservoir action are not entirely clear but apparently the bleaching action of sunlight on long exposure, coagulation and sedimentation, and probably some biological action, combine to lower color concentrations.

Obviously impoundments smooth out peak concentrations of color carried into them. Low stream flows receiving industrial color naturally show the highest concentrations. These flows are mixed to varying degrees in a reservoir with the pooled water therein with a resulting lowering of color concentrations. This equalizing action of an impoundment is obviously important in many aspects of water quality.

An unusual, and interesting, situation involving "color" developed on Parksville Reservoir in the fall of 1952. About the middle of September patches of black water were noted by local residents to be distributed over the surface of the reservoir. Within a week or 10 days the entire lake appeared to the casual observer to be filled with black ink. A brief investigation of the situation quickly revealed the material producing the coloration was not entering the lake from the tributaries, nor was the color apparent to the eye in water samples collected a few feet below the lake surface. Microscopic examination showed the "color" was produced by something in suspension rather than in solution. Algae were suspected of course and examinations of samples by several aquatic biologists provided the information that an algal bloom, probably of Microcystis, was the source of the apparent color. Concerned local residents were advised of the facts and were told the water would clear up as soon as cooler weather arrived. This prediction turned out to be true. Later it was learned that another reservoir, Great Falls, in the Cumberland River drainage, showed the same type of coloration at about the same time.

Such an event had not happened at Parksville in the memory of people who had lived near the lake for many years, nor has it happened again. Apparently all conditions were just right for a bloom of that particular genus of algae at that particular time. Fortunately such a combination of circumstances apparently does not occur very frequently.

Odor

Fortunately there is no major tributary of a storage impoundment in the

1. Churchill, M. A., "Natural Reduction of Paper Mill Color in Streams," Sewage and Industrial Wastes, 23, 661, May 1951.

Tennessee Valley so polluted as to have a noticeable, objectionable odor where it enters the pool. The few minor tributaries that are polluted to this extent carry such a small volume of water that the odor literally "gets lost" in the pools.

On the other hand, impoundment sometimes results in odors in the water discharged. Perhaps the most serious odor problem in connection with impoundments is that sometimes produced in local water supplies by algae growing in the pools. This problem has been discussed many times and will not be treated further herein except to say that such problems from storage impoundments in the Valley have been very minor. In water from reservoirs on the main Tennessee River, on the other hand, tastes and odors attributed to algae (but in at least some cases probably due to the mold-like bacteria Actinomycetes) have been intermittently evident at a number of water plants for a number of years.

Odors from the tailrace of a newly impounded reservoir can be an olfactory nuisance to any residents of the local area for one or possibly two summers. Below Nottely Dam the early releases contained enough hydrogen sulfide to darken white paint on some of the construction buildings still located near the tailrace.

Water samples collected throughout several verticals near the dam in Norris Reservoir late in the fall of 1936, following closure of the dam on March 4, 1936, revealed the presence of hydrogen sulfide near the reservoir bottom in concentrations up to 1 part per million (ppm). Similar sampling in January, March, April, and May of 1937 revealed no hydrogen sulfide at any depth. Samples in August 1937 showed concentrations of less than 0.2 ppm. Vertical circulation during the winter months completely aerates the water in even deep reservoirs (with one notable known exception in the Valley) to such an extent any existing odorous gases are released to the atmosphere, and of course additional hydrogen sulfide is prevented from forming.

Storage impoundments in the Valley are cleared just prior to reservoir closure of all trees and heavy brush that exist in the zone between full pool level and the usual level of maximum drawdown. Trees that project up into this zone are topped. Although the trees and brush are left (deep in the pool, below the summer thermocline) where they tend to deplete oxygen and produce hydrogen sulfide, after the pools have passed through a full annual cycle of operation but little additional influence on water quality seems to be exerted by the uncleared organic material.

Bacteriological Effects

From the sanitary engineering standpoint, storage impoundments are very desirable barriers between upstream bacterial pollution and downstream points of water use. As would be expected, the greatest reductions in bacterial concentrations are evident in the water released during the period of thermal stratification inasmuch as released water during this period has been in storage for several months. An examination of Figure 8 for Cherokee Reservoir shows coliform concentrations per 100 milliliter (ml.) in the inflow during April, May, and June of 1945 were usually in the range of 1,000 to 10,000, whereas in the outflow concentrations were, except for one of the 28 samples in this period, less than 50. During July, August, and September 1945, concentrations in the outflow were somewhat higher, getting up to a

maximum of 240 per 100 ml. During October, November, and December, concentrations in the outflow were lower again, being less than 100 in all samples in this period. During January, February, and early March of 1946, when periods of retention were much shorter and water temperatures lower than in the stratified periods of the year, concentrations in the outflow were frequently in the range of 100 to 1,000 and one sample in this period showed 1,600 coliforms per 100 ml.

The reductions noted above for Cherokee are undoubtedly much less than actually occurred in water passing through the pool inasmuch as the untreated sewage from Morristown, with a sewered population of 12,000 people was discharged at a low elevation into Cherokee Reservoir 23 miles above the dam. The coliforms sampled in the inflow to the reservoir came principally from Kingsport, Tennessee, a city with a sewered population of 18,000 people located about 40 river miles above the head of Cherokee Reservoir. (A sewage treatment plant is now under construction for Kingsport.)

Figure 9 for Douglas Reservoir reveals a reservoir effect on coliforms much the same as shown by Figure 8 for Cherokee. However, for Douglas Reservoir there are two other major tributaries, the Nolichucky and Pigeon Rivers, in addition to the French Broad River. The following tabulation indicates the relative sizes of the three tributaries, the arithmetic mean coliform concentrations found in each river, and the mean concentration in the penstock at Douglas Dam, for the year covered by Figure 9.

EFFECT OF DOUGLAS RESERVOIR ON COLIFORM CONCENTRATIONS

Tributary	Drainage Area at Sampling Station Square Miles	Number Samples	Mean Coliform Concentration MPN per 100 ml.
French Broad	1,858	87	13,500
Nolichucky	1,686	85	11,650
Pigeon	680	88	18,500
Outflow			
Douglas Penstock	4,541	87	165

From Figure 9, and the above tabulation, it is quite apparent that Douglas Reservoir reduces coliform concentration about 99 percent, on the average. Naturally all this reduction is not assignable to strictly reservoir effects since some reduction would have occurred in the open river.

A notable reduction in coliform concentrations in the raw water of the Kingsport municipal supply was immediately evident following the closure of Boone Dam, some 12 river miles upstream from the water supply intake. Coliform concentrations dropped from an average level of about 6,000 per 100 ml. for the period before the dam was closed to an average level of approximately 600 per 100 ml. since closure in December 1952. The fact that the Bristol, Tennessee-Virginia, sewage treatment plant went into operation in January 1953 has not been overlooked in these considerations. However, the reduction in coliforms at Kingsport attributable to this plant is uncertain inasmuch as samples near the mouth of the creek receiving the Bristol plant effluent have shown no material reduction in concentration or total numbers of coliform. It appears that a regrowth of coliforms in this small stream may be occurring.

Sanitary-Chemical Effects

Biochemical Oxygen Demand (BOD)

When water is held in storage for a period of several weeks or several months it is inevitable that in the process the BOD of the water will be substantially reduced. Figure 10 shows a series of long-term (30-day) BOD curves for water entering and leaving Cherokee Reservoir during the year 1952. As indicated by the relatively low 5-day BOD values for the inflow it is apparent that the inflow to Cherokee is not grossly polluted but on the other hand some degree of pollution does exist. Assuming the inflow and outflow samples are typical, the long-term BOD of the inflow is reduced some two-thirds by storage in the pool.

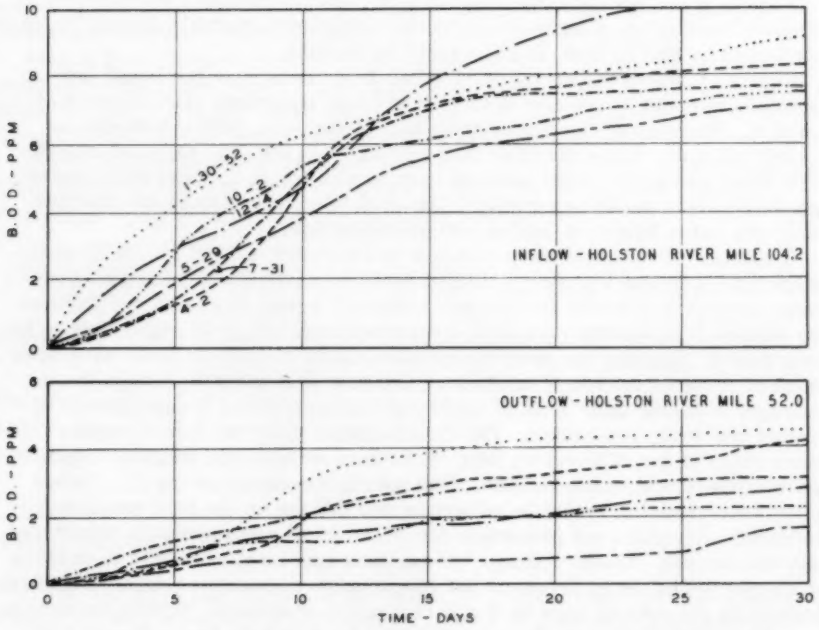
Figures 8 and 9 show reductions of 5-day BOD values by Cherokee and Douglas Reservoirs of samples collected at frequent intervals during the year April 1945 to March 1946, to be roughly 50 percent.

Figure 11 shows the variation in 5-day BOD throughout the length and depth of Cherokee Reservoir in the fall of 1943, two years after closure of the dam. Throughout the downstream half of the pool, BOD values did not exceed 1.2 ppm. Since the great mass of water in the pool sampled late in September and early in October had been in storage in the pool all summer, low BOD values would be expected. Many of the values are so low that the accuracy of the BOD test enters into consideration.

A number of verticals were sampled in Cherokee in 1946 for BOD with results as shown in Figure 12. These data are particularly interesting because a number of 5-day BOD values deep in the pool in August and September exceed D.O. concentrations at the same locations. It is impossible to believe that if sampling had been delayed five days, zero D.O. would have been found at these locations. The chances are that no detectable change (on the average) in either BOD or D.O. would have occurred in a 5-day interval of August and early September. The BOD samples were run full strength. Since some of the BOD values deep in the pool were in the range of 2 ppm, the results should be dependable. One possible explanation for this rather anomalous situation is that in collecting and setting up the BOD samples, bacterial organisms not present in the water itself were probably introduced into the sample. These "strange" organisms may have been able to produce an oxygen depletion in five days that the original organisms present could not. Also to be considered here is that according to Theriault[1] "nitrite formation may be inhibited when the dissolved oxygen content falls below 2 ppm," in samples incubated 10 days or more. In the reservoir the water under consideration had been "incubated" for several months so undoubtedly the second, or nitrogen, stage of the BOD was in very slow progress or had progressed as far as the low D.O. values would permit.

It is certain that algae and other microscopic aquatic organisms produce some effects on the BOD of reservoir waters. However, no attempt has been made herein to evaluate these effects quantitatively.

1. Theriault, E. J., "Detailed Instructions for the Performance of the Dissolved Oxygen and Biochemical Oxygen Demand Tests," Supplement No. 90, Public Health Reports, 1931.



EFFECT OF CHEROKEE RESERVOIR ON LONG-TERM B.O.D. -1952

FIGURE 10

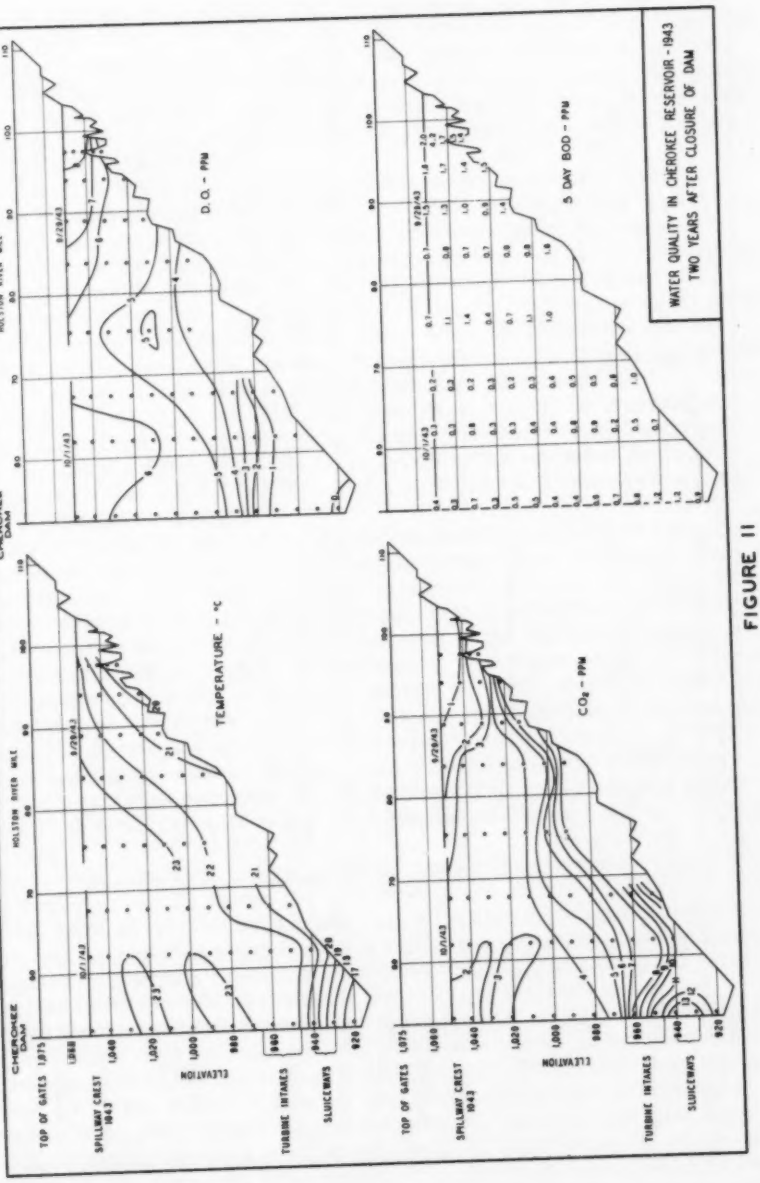

WATER QUALITY IN CHEROKEE RESERVOIR - 1943
TWO YEARS AFTER CLOSURE OF DAM
D.O. - PPM
5 DAY BOD - PPM
TEMPERATURE - °C
CO2 - PPM
CHEROKEE DAM
HOLSTON RIVER MILE
ELEVATION
TOP OF GATES 1075
SPILLWAY CREST 1043
TURBINE INTAKES
SLUICEWAYS

FIGURE 11

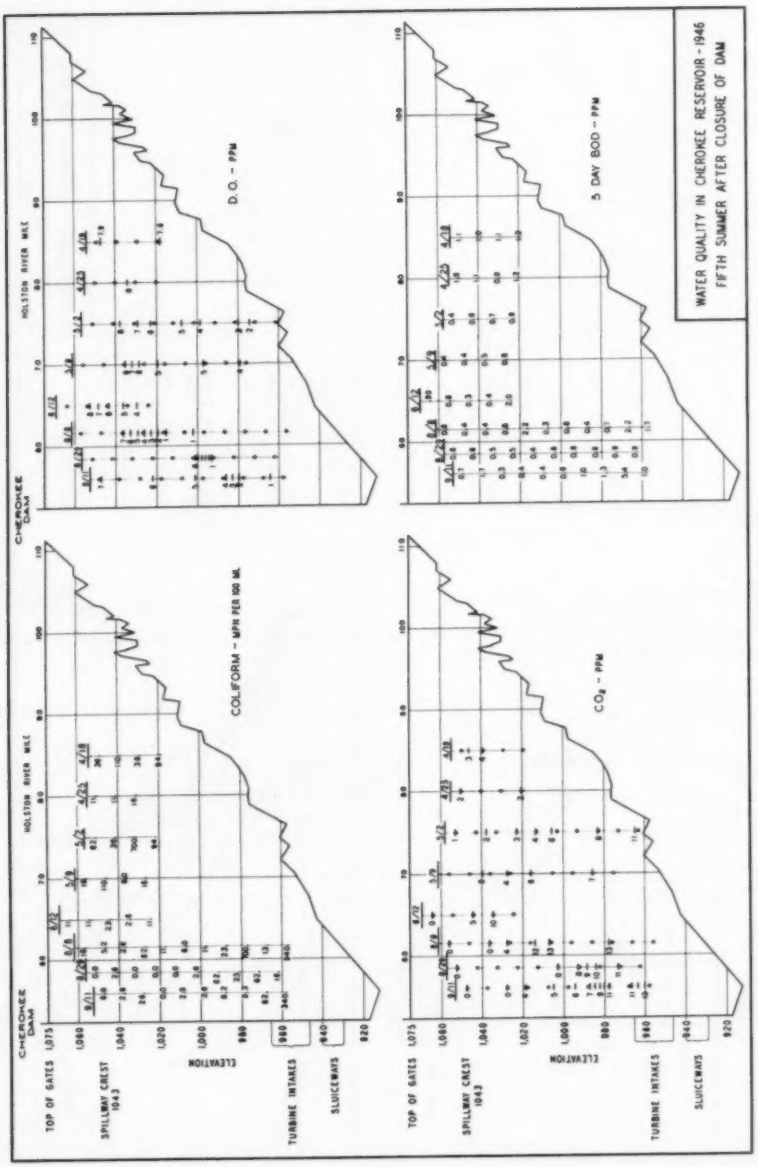

WATER QUALITY IN CHEROKEE RESERVOIR - 1946
FIFTH SUMMER AFTER CLOSURE OF DAM
D.O. - PPM
5 DAY BOD - PPM
COLIFORM - MPN PER 100 ML
CO_2 - PPM
CHEROKEE DAM
HOLSTON RIVER MILE
ELEVATION
TOP OF GATES 1075
SPILLWAY CREST 1043
TURBINE INTAKES
SLUICEWAYS

FIGURE 12

Dissolved Oxygen

Storage impoundments with low-level outlets release water during the period of thermal stratification that contains lower concentrations of D.O. than normally exist in the inflow. That this should be true is fairly apparent from the mechanics of flow through an impoundment as discussed earlier. Due to wind action, and diurnal temperature fluctuations, the surface layers of the lake, the epilimnion, down to the thermocline, are mixed and aerated. The temperature drops rapidly through the thermocline of course, and so does the D.O. concentration.

At this point in the discussion it should be noted that as summer progresses the thermocline sinks deeper and deeper into the depths of the pool, primarily because of the removal through low-level power intakes of the colder water of the hypolimnion, and secondarily because of the summer inflow of warm water that flows into the pool above the thermocline. The epilimnion thus gets very thick by the fall of the year and may actually extend all the way down to the level of the intakes. When the lower levels of the epilimnion reach the intake, the D.O. concentration in the outflow immediately jumps upward. Reference to Figure 5, showing Cherokee Reservoir temperatures in 1945 illustrates the progressive lowering of the thermocline, and the D.O. graph of Figure 8 shows the sharp increase in D.O. concentrations in September 1945 when the lower levels of the thickened epilimnion reached the intake level. The D.O. graph of Figure 9 illustrates the same event in Douglas Reservoir.

Since inflow to the pool during the spring and summer months normally enters above the thermocline, any pollution in the inflow is retained in the epilimnion and aerated therein during the warmer season of the year. Thus the upper layers of an impoundment during thermal stratification serve as a natural aerating device to satisfy at least part of the BOD of the pollution.

In the fall of the year when thermal density underflows exist, the inflows are naturally not aerated as the water moves relatively slowly along the bottom of the pool toward the low outlet. Mixing to a slight extent of the underflowing waters with the warmer water above prevents the D.O. in the underflow from dropping quite as fast as would otherwise occur. Underflows probably explain the reduction in D.O. concentration in the late September and early October releases shown for Cherokee in Figure 8 and for Douglas in Figure 9.

As the pool continues to cool in the fall, underflows are stopped and vertical circulation rapidly raises the D.O. level in the outflow. During the winter months, vertical circulation, a lower rate of BOD exertion due to lower temperatures, and usually a higher rate of inflow (thus providing more dilution for upstream pollution), combine to produce high D.O. concentration levels in the entire reservoir and of course in the outflow.

When thermal stratification begins in the spring, vertical circulation is thereby halted. The pollution existing in the lake waters below the surface layers proceeds to eat into the available D.O. and thus produce low D.O. concentrations in the outflow during the long period of thermal stratification. It is well to point out here that the concentration of "natural" pollution included in surface runoff waters is great enough to lower the D.O. in the outflow in late summer to near zero. This statement is based on routine observations of D.O. made on the outflow of several reservoirs in the Tennessee Valley above which there is no significant quantity of domestic or industrial pollution.

For example, the watersheds of Nottely and Chatuge Reservoirs have no contributed domestic or industrial pollution, and the watersheds of Watauga and Norris Reservoirs have very minor quantities. Yet each of these pools produces water in the mid-summer of every year that shows a D.O. concentration of less than 2 ppm.

In the summer of 1946, a series of verticals was sampled in Cherokee Reservoir with results as shown in Figure 12. As indicated by the D.O. values on this chart, oxygen concentrations as late in the spring as May 9, were fairly high in all but the lowest levels of the pool. A month later, however, D.O. values were less than 4 ppm below a depth of about 40 feet. As draft on the pool lowered the thermocline, the vertical thickness of well aerated water increased such that about the middle of September, 4 ppm were found as deep as 65 feet, and only about 20 feet above the top of the power intakes.

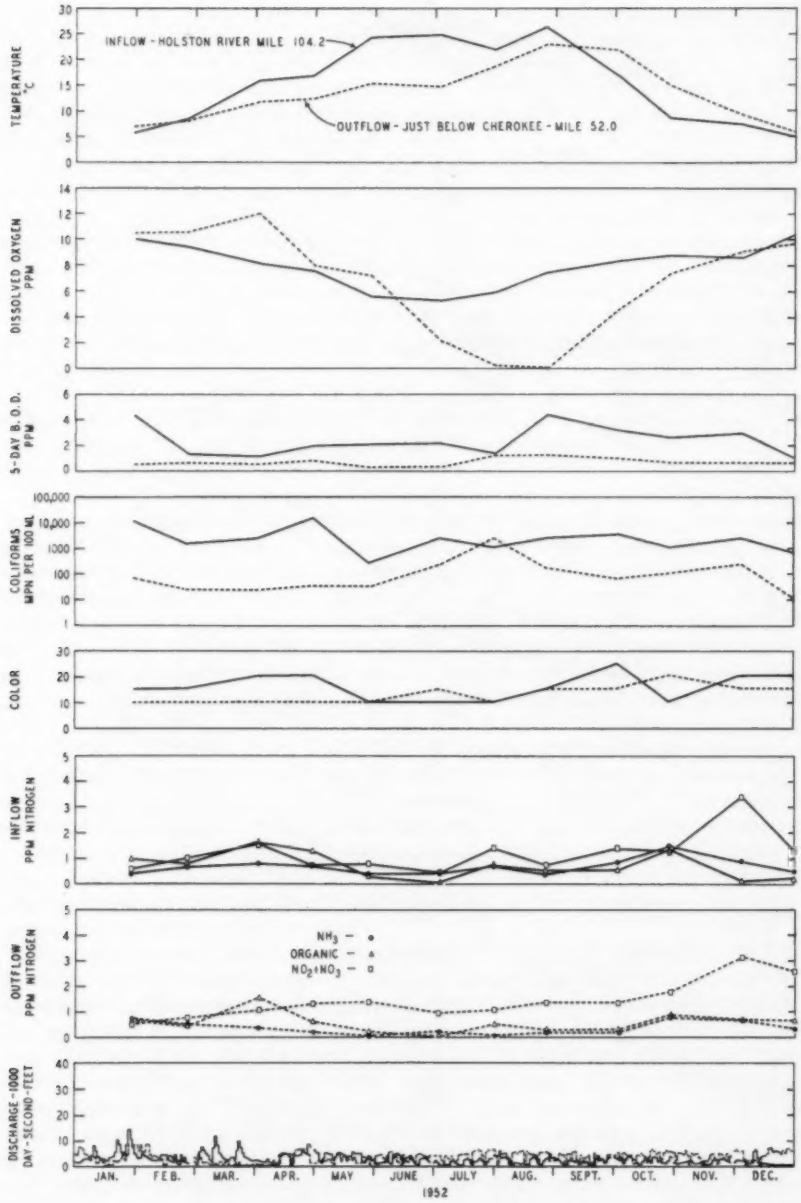
A series of monthly samples was collected from the inflow and outflow of Cherokee Reservoir with results as shown in Figure 13, during the year 1952, some 10 years after reservoir closure. D. O. concentrations in the inflow were not found below 5 ppm but were near zero in the penstock discharge in mid-summer.

In Fontana Reservoir, the deepest reservoir in the TVA system, D.O. concentrations in the outflow begin to drop in May and continue to recede until late September, as illustrated by the bottom graph of Figure 6 for the year 1955. By late September or early October, there is little thermal stratification left above the level of the intakes (judging from the years 1945 and 1946 shown also on Figure 6) and oxygenated waters from the lake surface are mixed into the lake as deep as the intake level.

Since Parksville Reservoir discharges through high-level intakes, the D.O. in the discharged water remains high all year, as shown by the lower graph of Figure 7.

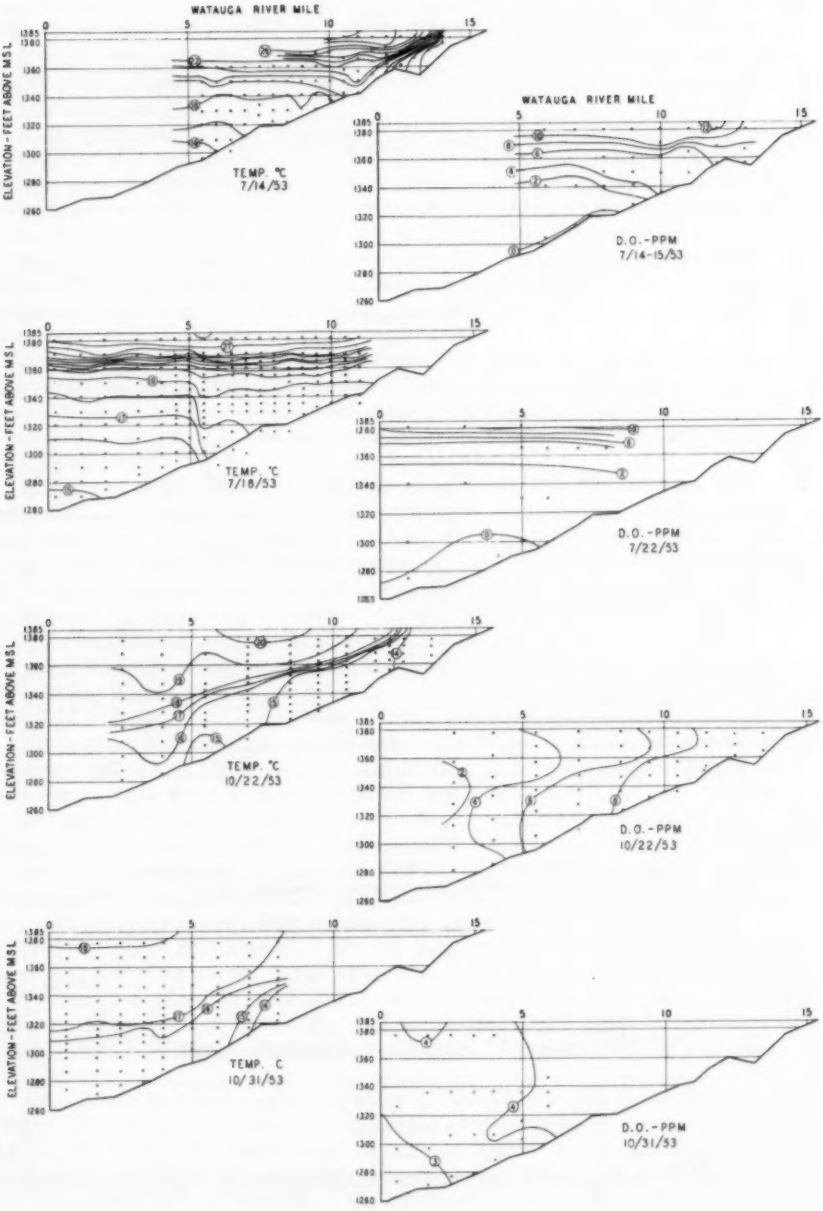
An interesting series of observations was made on Boone Reservoir in the summer and fall of 1953, as shown by Figure 14. The temperature and D.O. data shown here were obtained from the Watauga arm of the pool. The dam is located on the South Fork Holston River, to which the Watauga River is tributary, about a mile downstream from the mouth of Watauga River. As shown by the isotherms in the upper end of the Watauga arm of the pool for July 14, the inflow (principally from upstream Watauga Reservoir releases) was considerably cooler than the water in the surface strata of the pool. Consequently the inflow passed into the pool beneath the surface at its corresponding density level. (This interflow is discussed in some detail below.) The Watauga arm of the pool on July 22 was filled with water below a depth of about 30 feet, of very low D.O. (zero or nearly so) content. This exceedingly low D.O. is primarily the result of industrial pollution in the Watauga arm inflow.

The graphs of Figure 14 for October 1953 in Boone Reservoir show a vastly different thermal stratification picture, and D.O. situation. In October, the sloping isotherms parallel to the bottom clearly show the cold inflow was passing through the Watauga arm of Boone Reservoir as a density underflow. The odd shapes of the iso-D.O. lines for October 22 confirm the location of the underflow. Note the bottom strata of water on October 22 showed higher D.O. concentrations than that water on the surface of the pool. This rather unusual situation is produced partially by the underflow of aerated, but polluted, water from upstream, and also by the fact that rapid cooling of the



EFFECTS OF CHEROKEE RESERVOIR ON WATER QUALITY
TEN YEARS AFTER CLOSURE OF DAM

FIGURE 13



THERMAL STRATIFICATION & DISSOLVED OXYGEN CONCENTRATIONS
WATAUGA RIVER ARM, BOONE RESERVOIR — 1953

FIGURE 14

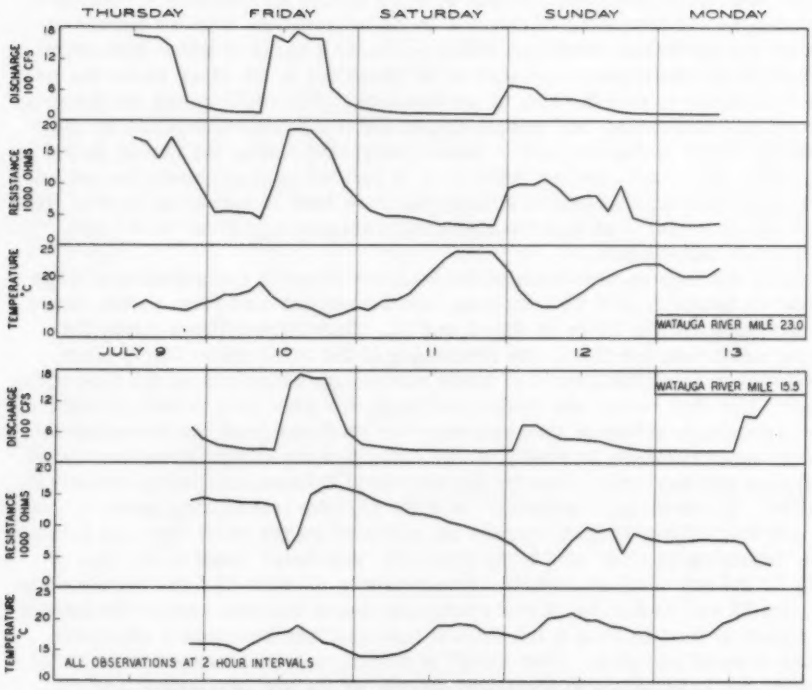
body of the lake was going on at the time these samples were collected. Low D.O. water was being brought to the surface from the middle depths faster than it could be aerated at the surface. Had the rate of vertical circulation been slower, (as would have existed if the atmospheric temperature had not turned so suddenly cold), surface aeration could have kept pace and such low D.O. concentrations on the surface as 3 and 4 ppm would not have been observed.

The interflow into Boone Reservoir mentioned in the second paragraph above is sufficiently important in its implications to justify a more detailed treatment. Since the interflow was actually traced into the pool by means of observations of electrical resistance on water samples, it is necessary to review the upstream conditions which produced a mass of water distinctive enough in its electrical resistance to be identified in the river above the pool and then followed into the pool as an interflow. Figure 15 shows discharges, electrical resistances, and temperatures for two sampling stations on the Watauga River above the head of Boone Reservoir during the period July 9 to 13, 1953. The upper station, Mile 23.0, is located approximately two miles downstream from a source of a fairly constant flow of industrial waste. This waste is such that it affects the electrical resistance of river water into which it is discharged.

Since the flow in this reach of the Watauga River is controlled to a large extent by Watauga (and Wilbur) Dam, the fluctuations are often rather sharp as indicated for the flows on July 9 and 10. Since higher flows dilute the waste more than low flows, the resistance of the river water fairly close downstream from the source of waste varies approximately as the flow of the river. For this reason the resistance graph for Mile 23.0 is very similar to the hydrograph of flow at this location. On the other hand, water temperature varies approximately inversely as the volume of river flow since the higher releases are warmed up less by the sun, local inflows, and warm industrial wastes. In travelling downstream to Mile 15.5 the translatory waves of July 10 and July 12 moved quite rapidly as indicated by the short time lag between the "beginning of rise" at the two stations. The water itself in the rise of July 12 did not move so rapidly. Consequently, at Mile 15.5 the highest flow on July 12 was composed of low resistance water that had passed the source of pollution at Mile 25 at a low rate of flow and thus received a relatively heavy dose of pollution. This "slug" of heavily polluted water was followed into Boone Reservoir and identified therein by its low resistance, and of course by the time of its entrance.

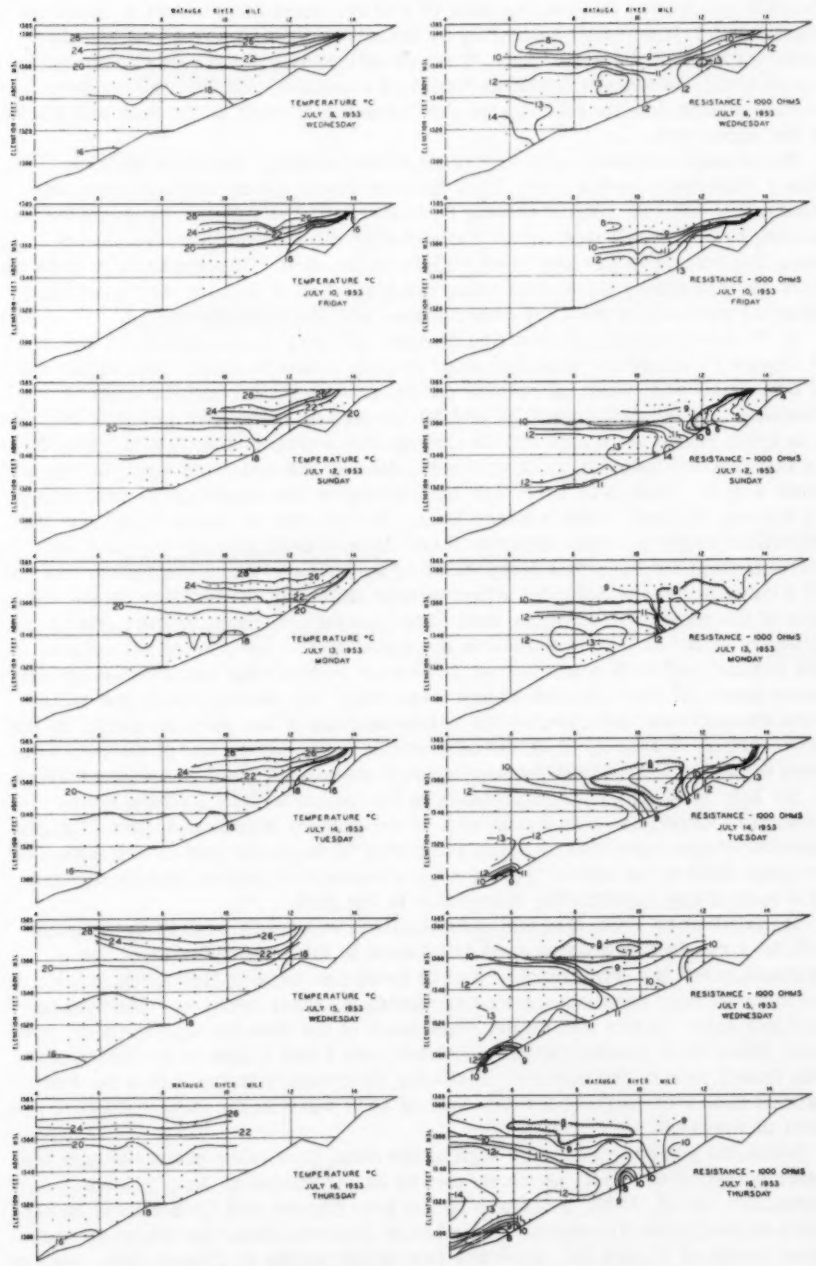
Figure 16 shows resistance values on water samples collected from the Watauga arm of Boone Reservoir during a series of days in July. Resistance values shown for July 8 and 10 indicate the relative character of the water in the upper end of the pool prior to the entrance of the "slug" on July 12. The rough outline of the slug followed into the lake is identified on the charts by short bars attached to the 8,000-ohm resistance line. By July 13 the slug had nearly detached itself from the reservoir bottom, having hit a layer of colder, denser water at about Mile 11 it could not displace, and was moving off down the lake at about elevation 1360. On July 15 and 16 the slug is shown to be completely detached from the bottom, thinned down in the vertical, and no doubt spread out more laterally as the pool widens out, and moving on downstream toward the dam at about elevation 1365.

A careful study of the resistance plots of July 10, 12, and 13, in Figure 16 will reveal a mass of water having a resistance of 13,000 ohms moved into



EFFECT OF FLOW VARIATION ON ELECTRICAL RESISTANCE OF WATAUGA RIVER BELOW ELIZABETHTON, TENNESSEE – JULY 1953

FIGURE 15



INTERFLOW IN BOONE RESERVOIR OF WARMER WATER OF WEEK-END INFLOW

FIGURE 16

the pool and flowed on down to Mile 10 and elevation 1340 before it found its density level (controlled primarily by temperature) and moved off at this elevation toward the dam. Thus these observed data illustrate that inflow to a pool seeks its density level, as would be expected, and then moves downstream at this density level under the influence of draft at the dam and inflow to the upper end.

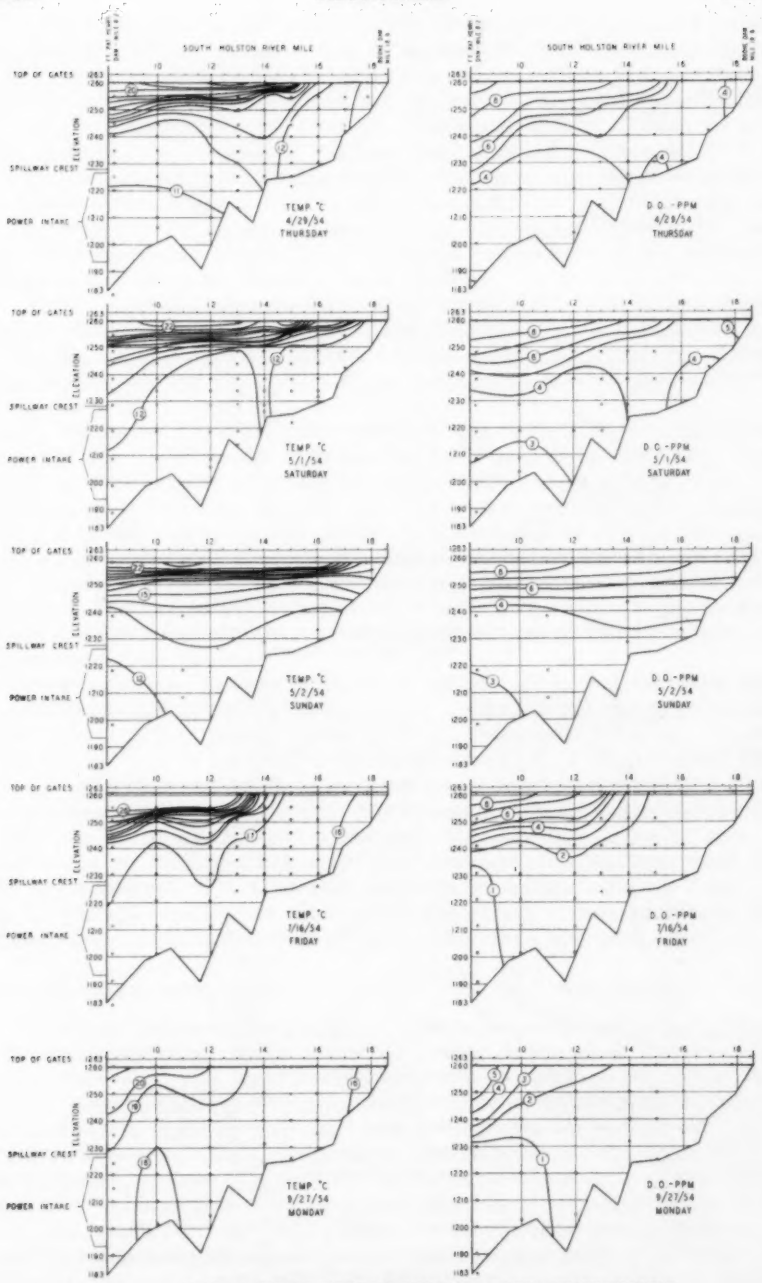
Small impoundments with low-level power intakes, like Fort Patrick Henry Reservoir on the South Fork Holston River, below storage impoundments, are not effective in raising D.O. levels in the inflow. As would be expected, flow through such small pools during the summer months passes along the bottom to the low-level outlets in the dam. Observations in 1954 on Fort Patrick Henry Reservoir bring out a number of factors worth noting. Selected portions of the 1954 observations are shown in Figure 17.

D. O. and temperature profiles of April 29, May 1, and May 2, at the top of Figure 17 illustrate what happened to D.O. concentrations inthe upper end of this small pool when inflow was cut from 3400 cfs throughout most of Thursday and Friday, April 29 and 30, to zero at 11:00 p.m. on April 30. Inflow from Boone remained cut off through the weekend to 8:00 a.m., May 3. As the profiles indicate, D.O. concentrations in the inflow on April 29 were about 4 ppm. This D.O. level was maintained in the underflow of cold water all the way to Fort Patrick Henry Dam. At this rate of inflow (3400 cfs) the underflow requires approximately three days to pass through the pool with thermal stratification conditions existing as in May. Since the inflow was cut off Friday night, the Saturday observations show the warm water on the surface of the main portion of the pool to be moving upstream in the surface strata in order to take the place in the upper end of the pool of the colder, and denser, inflow of the previous day which on Saturday was sliding into the lower levels of Fort Patrick Henry Reservoir. By Sunday, the warm water from downstream had covered the entire surface of the pool, as shown by the observations of May 2. D.O. concentrations in the upper end of the pool rose from 4 ppm to over 6 ppm during this upstream movement of surface waters.

By July 1954, D.O. concentrations in the inflow to Fort Patrick Henry Reservoir were less than 2 ppm and, in the outflow less than 1 ppm. Oxygen concentrations were thus reduced in flowing through the pool by the action of residual BOD in the inflow, by the oxygen demand of bottom sediments, and by a lack of any appreciable reaeration in the pool.

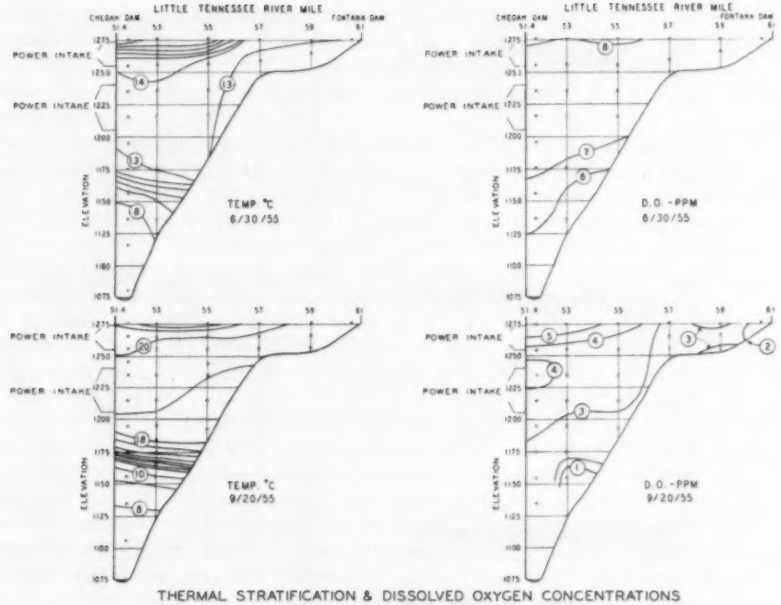
By September 1954, thermal stratification was much weaker in the pool and, as a result of the decreased difference in the temperatures of the epilimnion and the hypolimnion, and to some increase in flow from Boone, the underflowing hypolimnion was occupying a larger cross section than in May and July. There was no net reaeration of the flow through the pool, however, since D.O. concentrations were between 1 and 2 ppm in the inflow and less than 1 ppm in the outflow. Five-day BOD values in the inflow to Fort Patrick Henry throughout the summer of 1954 were in the range of 2 to 4 ppm most of the time.

When the power intakes are high in the dam, flow takes place through the upper strata of the pool, as illustrated by observations of June 30 and September 20-21, 1955, in Figure 18 for both Cheoah and Calderwood Reservoirs on the Little Tennessee River below Fontana Dam. As shown by the upper graph of Figure 18, there are two intake levels in Cheoah Dam, both of which are fairly high. Flows through Cheoah and Calderwood Reservoirs for several days prior to the observations of June 30, 1955, were fairly steady

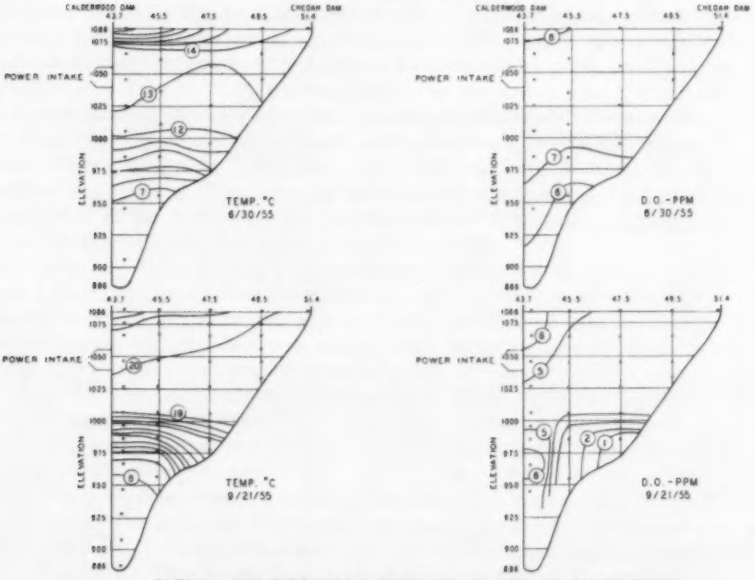


THERMAL STRATIFICATIONS & DISSOLVED OXYGEN CONCENTRATIONS
FORT PATRICK HENRY RESERVOIR - 1954

FIGURE 17



THERMAL STRATIFICATION & DISSOLVED OXYGEN CONCENTRATIONS
CHEOAH RESERVOIR - 1955



THERMAL STRATIFICATION & DISSOLVED OXYGEN CONCENTRATIONS
CALDERWOOD RESERVOIR - 1955

FIGURE 18

near 5000 cfs. The lower portion (below elevation 1175) of Cheoah Reservoir was not used by the moving waters. The average water velocity through the effective cross section of the pool in the reach from Mile 55 to the dam at Mile 51.4 was approximately 0.15 foot per second, based on approximate cross sections and a flow of 5000 cfs. The mean velocity through the effective lower end of Calderwood was also about 0.15 foot per second.

This situation illustrates the fact that even though the water released from Fontana in June is much colder than local runoff, it still flows through the upper levels of Cheoah and Calderwood inasmuch as the water below the high-level intakes in Cheoah and Calderwood still has a winter temperature, the same as that below the intake level in Fontana.

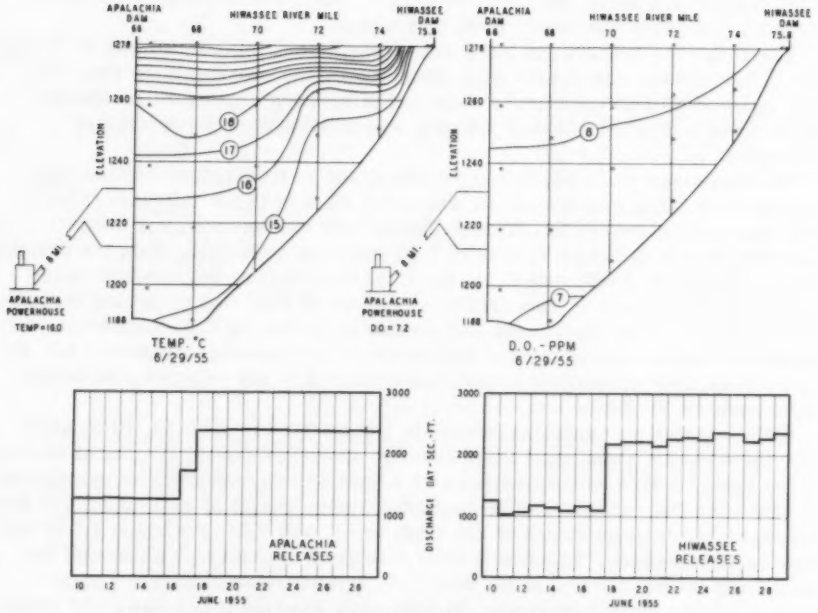
The D.O. concentration in the Fontana scrollcase on June 30 was 6.30 ppm and in the tailrace one-fourth mile downstream the concentration was only 7.20 ppm, or 72 percent of saturation at the existing temperature. Below Calderwood a concentration of 7.6 ppm was observed, or 75 percent of saturation.

By September 20, 1955, D.O. concentrations in the Fontana outflow had dropped to 1.20 ppm in the scrollcase and 1.62 ppm in the tailrace. There was appreciable reaeration through Cheoah and Calderwood, and below Calderwood a D.O. concentration of 5.90 ppm was observed. With the existing level of flows, it is estimated that the total time of flow through both pools was about eight days. A reaeration coefficient of 0.05 was computed through the two pools. (The coefficient was computed as the log D.O. saturation deficit at Fontana minus the log deficit below Calderwood, divided by 8.) No doubt most of the measured reaeration occurred in the relatively turbulent upper ends of the pools.

Observations on Apalachia, shown in Figure 19, for June 29, 1955, show flow through this small pool is by density underflow during the warm season of the year. A D.O. concentration of 7.2 ppm was observed in the scrollcase of Hiwassee Dam at the head of Apalachia Reservoir, 7.35 ppm about 100 feet downstream from the mouth of the draft tubes, and 7.38 ppm about 1,100 feet farther downstream. There was little change in concentration through the main body of the pool and at the dam D.O. concentrations were 7.7 ppm throughout the moving stratum. At Apalachia powerhouse, some eight miles farther downstream, D.O. concentrations in the scrollcase were down to 7.2 ppm. The apparent loss of about one-half ppm may represent demand of slime materials known to exist on the walls of the eight-mile tunnel.

Free Carbon Dioxide

In an impoundment, free carbon dioxide is produced primarily by biochemical decomposition of organic materials present in the water. In the epilimnion, much of the CO_2 produced is released to the atmosphere as the water is "turned over" by diurnal temperature fluctuations, and by wind action. In the surface layers of the epilimnion, algae, through photosynthesis, are very effective in reducing CO_2 concentrations (and thus raising the pH). In the hypolimnion, the free CO_2 produced by bacterial metabolism is kept in solution by the greater hydrostatic pressure existing at all points below the thermocline. Since algal use of CO_2 below the thermocline is relatively minor, and little if any can escape, CO_2 concentrations may build up to rather high values in the lower levels of a deep impoundment during periods of thermal stratification.



THERMAL STRATIFICATION & DISSOLVED OXYGEN CONCENTRATIONS
APALACHIA RESERVOIR-1955

FIGURE 19

Perhaps the best available illustration of the changes in CO_2 concentration produced in a reservoir is shown by Figure 12 for Cherokee Reservoir. Here in the summer of 1946 the surface layers of water, down to a depth of 55 feet on August 29, showed high pH values (8.0 to 8.2), a total alkalinity of about 80 ppm, and no free CO_2. On August 5, concentrations of CO_2 as high as 30 ppm existed near the bottom of the reservoir. Values plotted on Figure 12 are not this high inasmuch as the record shows CO_2 was determined in the field by titration (some CO_2 may have escaped in the titration process) for the 1946 observations. Graphic determinations[1] of CO_2 concentrations based on pH and total alkalinity indicate up to 30 ppm existed although the titration procedure indicated only 13.5 ppm as a maximum. Near the bottom, pH values of 6.8 were observed with alkalinity values near 100 ppm.

Additional data on the effects of impoundment on CO_2 are given by Figures 8, 9, and 11. The concentrations shown were also obtained by field titration with N/44 sodium hydroxide to the phenolphthalein end point.

As shown by Figure 8, CO_2 concentrations in the summer of 1945 were in the range of 9 to 12 ppm (by titration, but 13 to 18 by graphic determination) in the water released from Cherokee Dam at Holston River Mile 52.2. In flowing downstream to Holston River Mile 1.8 the graphically determined CO_2 concentrations were reduced to concentrations in the range of 4 to 6 ppm. Since the partial pressure of CO_2 in the open atmosphere is normally very low, most of the free CO_2 in the discharged water was released to the atmosphere. (Inflow to Cherokee in 1945 showed graphically determined CO_2 concentrations were also in the 4 to 6 ppm range.)

Nitrogen

Perhaps the most interesting available data on the effects of impoundments on the various forms of nitrogen were obtained from samples in, and downstream from, Boone Reservoir. The inflow to Boone carries a heavy load of ammonia from an upstream industrial plant. Time of flow from the plant to the reservoir is so short it precludes much conversion of ammonia to nitrites and nitrates in the open river. When this waste enters the lower levels of the pool, in a density interflow, as discussed above in connection with D.O., some conversion takes place. However, when the available D.O. is used up, no more oxidation can occur until the water is released from the Watauga arm of the pool and has an opportunity to mix with the underflowing waters of the South Fork Holston arm of the pool. These waters contain D.O. so conversion to nitrites and nitrates can proceed, assuming a sufficient supply of the nitrifying organisms, Nitrosomonas and Nitrobacter, is present.

One of the unusual aspects of this situation in the Watauga arm of Boone Reservoir is that although D.O. concentrations in the lower levels were zero in 1953, the water in samples from the lower levels did not have an odor of hydrogen sulfide. That this unusual condition could exist is apparently due to the fact that the carbonaceous demand of the organic pollution present was satisfied by the available D.O. and the nitrogenous demand was of course biochemically unable to reduce sulfates to sulfides. The possibility also exists that if the available D.O. in the inflowing waters were not sufficient to supply the carbonaceous demand, some reduction of the nitrates that were present

1. Moore, E. W., "Graphic Determination of Carbon Dioxide and the Three Forms of Alkalinity." Journal AWWA, 31:51 (January 1939).

(by upstream oxidation) would supply the needed oxygen and thus prevent odors.

From this discussion it is apparent that an ammonia waste can pass through a reservoir and have a very considerable oxygen demand still remaining. Such a demand would reduce the rate of net gain in oxygen concentrations in the open river below the dam. Obviously any oxygen tied up in the nitrates and nitrites of the outflow would be available for control of odors that might be produced by downstream organic pollution.

Figure 13 illustrates the fact that low concentrations of ammonia and organic nitrogen passed through Cherokee Reservoir in 1952. There was some conversion to nitrites and nitrates but not as much as would be expected. The concentration of nitrifying organisms may have been too low for any more conversion.[1] No data are available to indicate the existing concentrations of such bacteria.

Mineral Quality Effects

Iron and Manganese

One of the questions most frequently asked regarding the effects of impoundments on downstream water quality concerns iron and manganese. This question can be answered by the simple statement that with one important exception, no significant troubles in downstream water supplies have been experienced below any of the TVA storage projects.[2]

Iron and manganese in the soluble (ferrous and manganous) forms cause staining troubles in municipal water systems. When these forms are oxidized to the ferric and manganic states prior to filtration, the resulting particulate matter can be filtered out. In an uncontrolled open river, any soluble iron and manganese brought into the stream in ground water is oxidized by the dissolved oxygen of the stream and thereby converted to an insoluble state. However, should the stream flow into a deep reservoir, the oxidized forms of these two minerals may be reduced to a soluble state. All iron and manganese in the water which is caught below the thermocline in the spring of the year when stratification begins is subject to being put into solution, even though the particulate matter may have settled to the bottom of the pool. Furthermore, any oxidized iron and manganese which is brought into the pool in the warm season may settle out of the epilimnion into the hypolimnion and there be subject to solution.

Fortunately for the water supplies of the upper Tennessee Valley area, significant commercial deposits of manganese are apparently limited to the northeastern portion of the Valley,[3] in the Holston and Nolichucky River drainages. These major deposits occur along the western front of the Unaka Mountains. A number of other areas have minor deposits but they are of less significance. Iron deposits are fairly widespread over the Valley.

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1. Dr. A. M. Buswell, University of Florida, Private communication dated February 29, 1956.
2. Kittrell, F. W., and Thomas, F. W., "Effects of River System Development on Water Quality in the Tennessee Valley," Journal AWWA, 41, 9, 777, September 1949.
3. Industrial Resources of Tennessee, Tennessee State Planning Commission, Nashville, Tennessee, 1945.

It might be expected from the distribution of manganese deposits, and the locations of manganese mining and ore washing operations, the most serious water supply troubles due to manganese would occur below South Holston with perhaps less difficulty below Boone and Fort Patrick Henry, Cherokee, and Douglas Reservoirs. To date, the only significant problem to develop has been at the Bristol, Tennessee, water plant. This plant has its intake on the South Fork Holston River one mile below South Holston Dam and powerhouse. As shown by Table 1, South Holston Reservoir when full is some 250 feet deep at the dam. The power intake comes off the pool about 150 feet below full-pool level, and 100 feet above the bottom of the original river channel at the dam. During periods of normal operations at South Holston Dam, water released through the single power unit supplies municipal use at Bristol. To provide for continuity of supply at Bristol when the turbine must be unwatered for routine inspection and maintenance work, a small Howell-Bunger valve was installed at the bottom of the dam in the diversion tunnel used during dam construction to by-pass the river.

The dam was closed in November 1950 and the low-level outlet was not needed until February 8, 1952, for the first routine inspection of the turbine. The water released was of satisfactory quality for conventional treatment by the Bristol plant. The second inspection was made during the period October 25 to November 1, 1954, and during this period operating experiences at the Bristol filter plant are summarized below from a letter written by the filter plant operator, Mr. Odell W. Gray.

1. Saturday, October 23. The filter plant operators were notified by TVA that water from South Holston Reservoir would be shut off Monday, October 25, to Friday, October 29. The operators were asked to call TVA for water in case of water shortage at the raw water intake and to call when the intake pool was full in order not to waste water.

2. Wednesday, October 27. Water was low at raw water intake, pumps were pulling air. Pumps were shut off four hours. TVA was called for water. The water received was high in color, turbidity, taste and odor. The chlorine demand was 15 ppm. It was necessary to increase alum and chlorine rate of feed and start the application of activated carbon.

3. (a) Friday, October 29. Water was low at raw water intake. TVA was called for water.

(b) At 9:30 p.m. evidence of presence of manganese in raw water noted by operator on duty. Six ppm manganese, and 15.0 ppm iron were present in raw water. Concentrations in finished water reached a high of 2.0 ppm manganese and 0.1 ppm iron. The operators realized the chlorine feed control apparatus could not supply the demand and so obtained a diffuser with which they were able to feed an additional five pounds per hour by keeping cylinder warm. By the use of the additional chlorine for oxidizing and by throttling the raw water pumps to 2 MGD in order to obtain a rate of 30 ppm chlorine applied, they were able to reduce the manganese concentration from 2.0 ppm to 0.8 ppm in the finished water.

4. Sunday, October 31. Water was low at raw water intake. TVA was called for water. At 4:30 p.m. manganese 5.0 ppm, iron 15.0 ppm in raw water. Manganese 0.8 ppm, iron 0.1 ppm in finished water.

5. Monday, November 1. At 2:00 p.m., manganese was 6.0 ppm (off color),

and iron was 3.0 ppm in raw water. Manganese 0.0 ppm, iron 0.0 ppm in finished water. The turbine at South Holston Dam was operated for short period Monday p.m.

6. Tuesday, November 2. At 2:00 p.m., manganese was 0.6 ppm in raw water, 0.0 ppm in finished water. At 8:30 p.m. manganese 0.5 ppm in raw water, 0.0 ppm in finished water.

From Tuesday, November 2, to November 11, the operators had a normal raw water with manganese concentrations of 0.2-0.3 ppm and iron concentrations of 0.1-0.2 ppm.

During the above period the operators had from 75 to 100 complaints and inquiries concerning the water with variations of from a mere comment to threats to sue for damages. Many people suffered damages to wearing apparel, linens, etc. from the manganese stain which brought threats to sue. The City of Bristol, Tennessee, suffered considerable damage due to the additional chemicals used in treating the water. The experience proved to be most embarrassing to the City Commissioners as well as to the entire water department personnel.

An investigation of the situation existing in South Holston Reservoir included the collection of a series of water samples from the pool at a location just upstream from the dam. The pertinent findings on these samples are shown by the graphs in the upper left section of Figure 20. The extremely high concentrations of iron and manganese at the bottom of the pool, 50 ppm iron and 18 ppm manganese, were at the same level as the low-level outlet in the dam.

At the elevation of the power intakes, 100 feet above the bottom of the pool, the iron and manganese concentrations were very low as indicated by the graphs. (The reason is not clear as to why D.O. concentrations were so low in the region of the thermocline, and then increased somewhat just below. Dead algae and other decaying aquatic organisms collecting, temporarily at least, at this level of sharply increased density, may have been the cause or a density interflow of muddy water some time a week or so prior to the sampling may have been the cause.)

The lowest strata in the pool were practically devoid of oxygen, as would be expected in the layer of soluble iron and manganese. It is of interest to note the water samples collected from near the bottom of the pool were murky, but not colored. However, after some handling and after standing in the laboratory for a few days, the bottom samples acquired a typical iron color that was very dense.

Although difficulties at the Bristol plant cleared up after normal discharges were resumed through the power intake, it was expected that as the lake began to circulate vertically all the way to the bottom, there might be some noticeable increase in iron and manganese at the Bristol water plant. Such an increase was not reported. Another set of samples was collected from the reservoir the following March 10 with results also shown in Figure 20, at the lower left. Surprisingly, oxygen concentrations were still zero at the very bottom, and low for about 20 feet above the bottom. Correspondingly, high iron and manganese concentrations were still present in the bottom waters.

To determine why vertical circulation was not complete at this time of the year, a total solids determination was run on all samples. The bottom

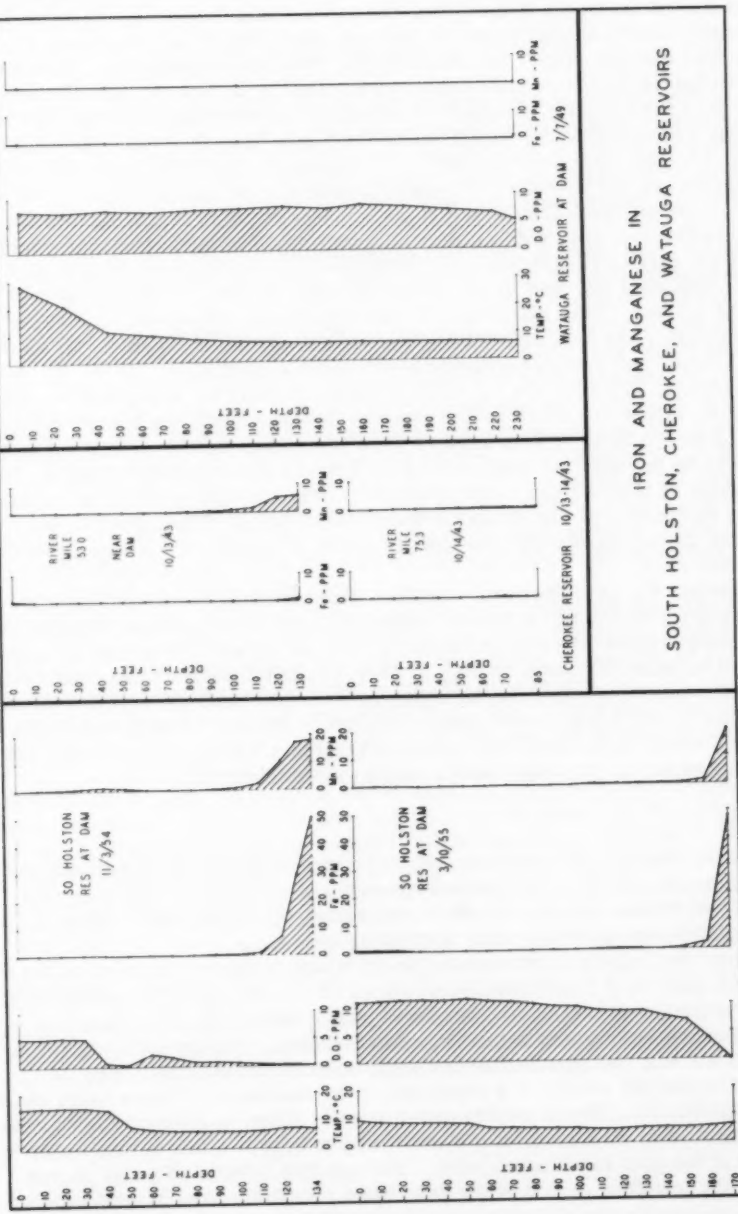

IRON AND MANGANESE IN
SOUTH HOLSTON, CHEROKEE, AND WATAUGA RESERVOIRS
SO HOLSTON RES AT DAM 11/3/34
SO HOLSTON RES AT DAM 3/10/35
CHEROKEE RESERVOIR 10/13-14/43
RIVER MILE 530 NEAR DAM 10/13/43
RIVER MILE 753 10/14/43
WATAUGA RESERVOIR AT DAM 7/1/49
DEPTH - FEET
TEMP - °C
D.O. - PPM
Fe - PPM
Mn - PPM

FIGURE 20

samples were materially higher in mineral content. The increased mineralization in the bottom water together with its relatively low temperature, produced a stratum on the bottom that was more dense than it was possible for the upper waters to attain even at the maximum density temperature, 4°C. This then was the reason for the failure of the lake to completely "turn over."

Routine water temperature observations by the Hydraulic Data Branch of TVA have consistently revealed the water at the very bottom of the lake to be slightly warmer than that higher up in the pool. Since all water has been above 4°C, the increased density due to dissolved minerals apparently holds the answer to why the warmer water can stay on the bottom.

An investigation of the iron and manganese situation in Cherokee was made in October 1943 with results as shown in the middle section of Figure 20. Very little iron was found but manganese concentrations up to 6 ppm were found near the dam in the very bottom of the pool, below the level of the turbine intakes. This material was probably slowly mixed with the upper waters during the following winter and discharged from the pool. No complaints were received from downstream water suppliers.

Figures 8 and 9 show a year's experience concerning manganese in the inflow and outflow of Cherokee and Douglas Reservoirs during the period April 1945 to March 1946. These results show the concentration of total manganese, and do not indicate how much of the total is in the soluble reduced form. The study by Kittrell and Quinn previously referred to indicates that breakpoint chlorination at the Knoxville water plant, below both Cherokee and Douglas Dams, apparently precipitated some, if not all, of the manganese on the filter sand.

Although Watauga Reservoir is close geographically to South Holston Reservoir, geologically it is well separated since no significant deposits of manganese appear to exist on its watershed. A series of samples throughout the entire depth (230 feet) on July 7, 1949, revealed insignificant concentrations of iron and manganese, as shown by the right-hand portion of Figure 20. An industry requiring practically the complete absence of manganese in its process water is located a few miles downstream from Watauga Dam. No difficulties due to iron and manganese have been reported.

General

The equalizing, or smoothing, effect a storage reservoir has on mineral quality in general is rather obvious from the basic function of the project. Peaks and valleys of concentrations are smoothed out so that a water of more uniform mineral quality results downstream.

A good example is furnished by the variation in chloride content in the inflow and outflow of Cherokee Reservoir as shown in Figure 8. Industrial pollution upstream from the pool produced peak concentrations, during the period of observations shown here, up to 300 ppm. The peak concentration in the outflow was 136 ppm in October when underflows were existing.

The beneficial effects of a reservoir in connection with water hardness are quite substantial. Runoff during above-normal flows is obviously low in hardness, as it is in all dissolved minerals, and of course much of this water is stored in the pool for later release. The relative volume of water stored during the low-flow period of the year when relatively hard ground water makes up practically all the inflow, is small by comparison. Water supply intakes downstream from the reservoir are spared the long period of high

mineralization that usually occurs in the summer and fall and instead are supplied with water of much lower mineralization.

Reaeration Below Storage Impoundments

A subject in which there is widespread interest, but on which there is little factual information available, is the rate at which deoxygenated water released from impoundments becomes reaerated in river channels downstream.

Since the released water ordinarily has a very insignificant BOD remaining, the rate of reaeration is not retarded, (and its measurement confused,) by the demand for oxygen of upstream pollution.

Figure 21 shows observed reaeration in the lower Holston and the lower French Broad Rivers in 50 and 25 miles, respectively, of open river channel. As indicated, local inflow is very small into both river reaches. No significant quantities of pollution are added in the local inflow. BOD values are indicated on Plates 8 and 9 to be very low, being ordinarily less than 2 ppm in 5 days. But little information is available on the time of flow through these river reaches. It is known[1] from actual observations that water flowing at 7,900 cfs requires 24.5 hours to traverse this 50-mile reach of the Holston River, at an average velocity of 3 feet per second. It is significant to note from Figure 21 that during the period of greatest D.O. deficit at the dam, the extent of reaeration was about 6 ppm in the 50-mile reach, starting near zero at the dam. Although the pickup was 6 ppm, or slightly more at times, the water still lacked some 2 ppm of reaching saturation for the temperatures existing at the lower end of the reach.

The extent of oxygen pickup in the lower French Broad during August 1945 was about 4 ppm, starting with 1 ppm at the dam. Here also, saturation was about 8 ppm. Thus there was a deficit of 3 ppm (about 37 percent of saturation) still remaining at the lower end of the 25-mile reach.

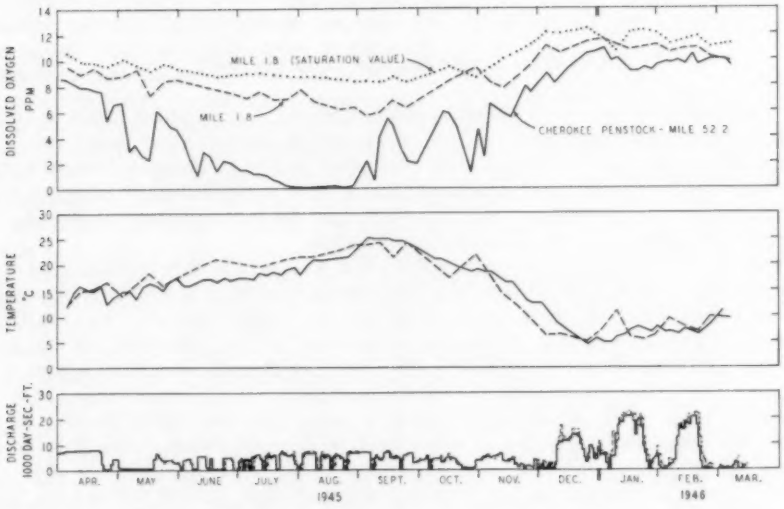
Figure 22 shows low-water profiles of the lower Holston and lower French Broad Rivers. The slope of both rivers in these reaches is approximately the same, about 2.2 feet per mile.

Reaeration at 7400 cfs in the lower Holston on September 20-21, 1949, progressed rather uniformly from a point 0.2 miles below the dam (Mile 52.0) to Mile 1.8, increasing from near 2 ppm below the dam to 6.4 ppm at the lower end of the reach. The exact time of travel is not known but it cannot be but slightly longer than that for 7900 cfs, or about 25 hours. On this basis, the reaeration coefficient for the entire reach is computed to be 0.48. In these computations the reaeration coefficient is computed from the formula:

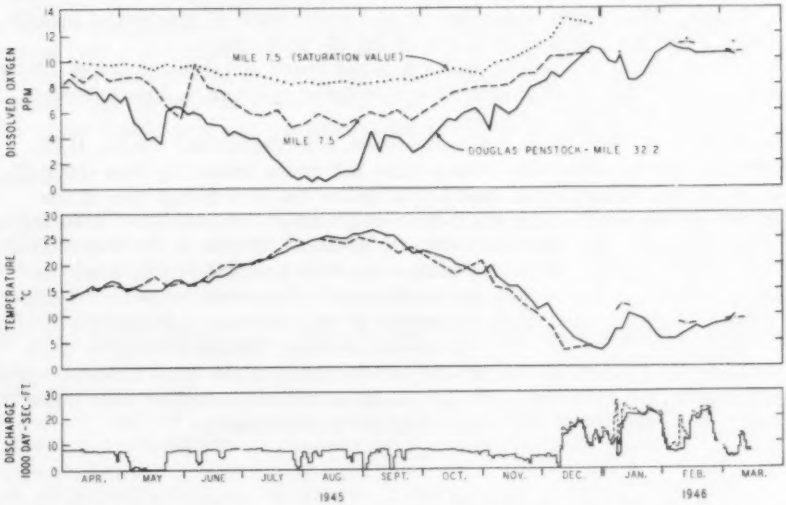
$$\text{Reaeration Coefficient} = \frac{\text{Log D.O. Deficit at Sta. A - Log D.O. Deficit at Sta.B}}{\text{Time water travel Station A to B, in days.}}$$

In the lower French Broad River, more details of the time of water travel are available thus permitting the computation of the reaeration coefficient for the night observations of September 14, 1949, as follows:

1. Churchill, M. A., Discussion of "Translatory Waves," Transactions ASCE 1945, page 1229.

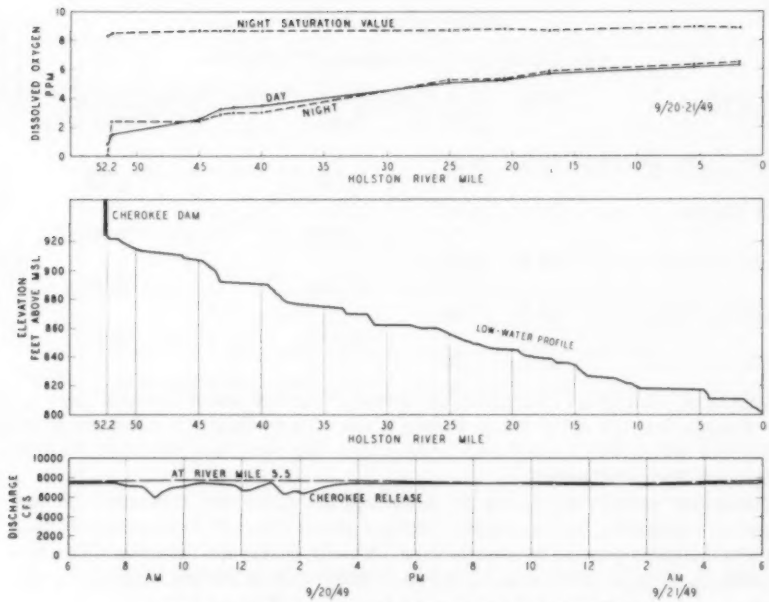


REAERATION IN 50 MILES OF HOLSTON RIVER BELOW CHEROKEE DAM

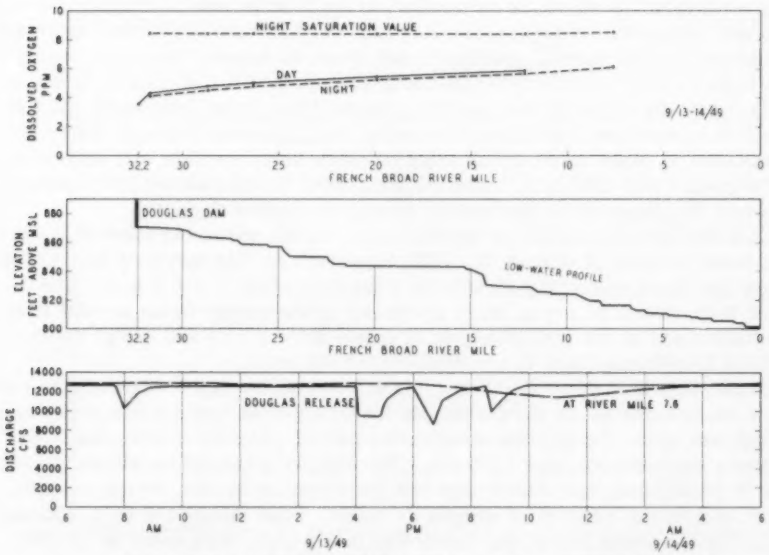


REAERATION IN 25 MILES OF FRENCH BROAD RIVER BELOW DOUGLAS DAM

FIGURE 21



REAERATION IN LOWER HOLSTON RIVER - SEPTEMBER 1949



REAERATION IN LOWER FRENCH BROAD RIVER - SEPTEMBER 1949

FIGURE 22

REAERATION IN LOWER FRENCH BROAD RIVER

September 14, 1949

For River Flow of Approx. 12,000 cfs

Location	Mile	D.O. ppm	Time Water Travel Days	Reaeration Coefficient (Darkness)
Bridge below Douglas	31.7	4.08		
			0.053	0.79
Kiker Ferry	28.7	4.48		
			0.043	0.84
Hodges Ferry	26.3	4.80		
			0.128	0.48
Dumplin Creek	19.9	5.29		
			0.167	0.44
Huffaker Ferry	12.2	5.72		

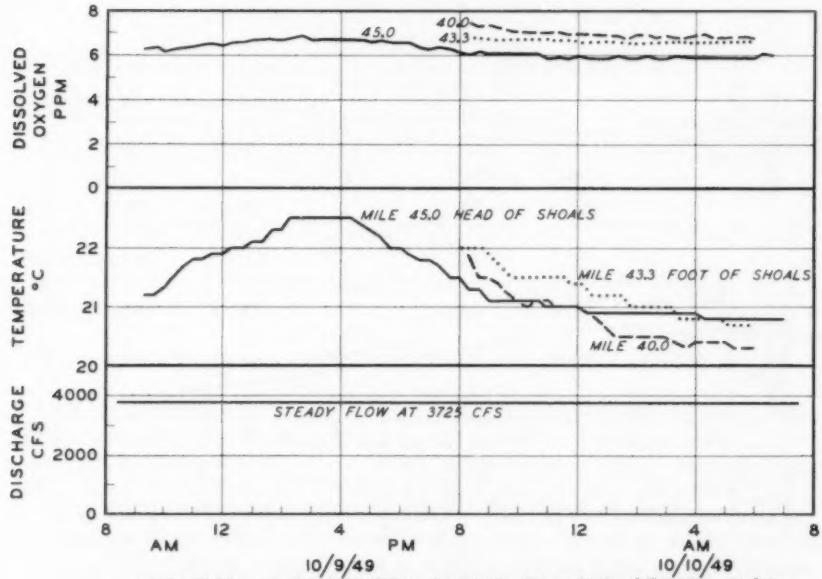
Apparently the long, flat pools in the two reaches below Hodges Ferry, even though connected by sharp shoals (at low flow) hold down the reaeration coefficient below that observed for the upper two reaches, between Douglas bridge and Hodges Ferry.

The upper graphs of Figure 23 illustrate the variation in reaeration observed at a point in Holston River some 7 miles downstream from the dam during a 24-hour period ot steady flow. The D.O. varied between 5.85 ppm and 6.90 ppm, apparently due to oxygen added during the daylight hours by algae.

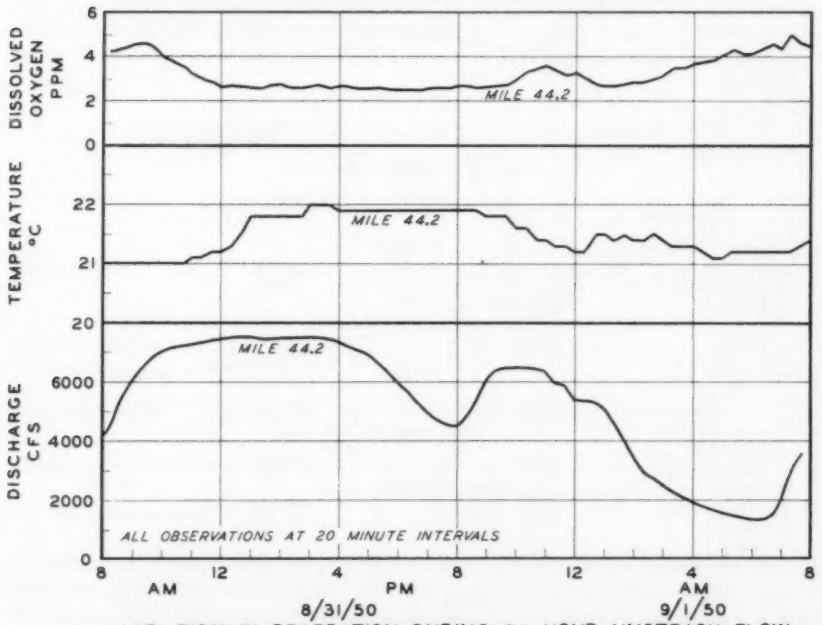
Contrasting with the steady-flow observations, data at the bottom of Figure 23 show the effect on reaeration in the 8-mile reach between Cherokee Dam and Mile 44.2 of varying the flow between 1300 and 7500 cfs. As clearly brought out in the curves, low flows pick up more oxygen (on a ppm basis) than higher flows in traversing the same distance. This of course is due to the fact that the lower flows require a longer time, have less depth and therefore less volume per unit of surface area, and a given particle of water has opportunity to make more round trips between water surface and stream bed in the given river distance. Relative roughness of the channel increases as the depth decreases thus increasing mixing at shallower depths.

Note the time lag shown by the increase in D.O. values at Mile 44.2 beginning about 10 p.m. of August 31, 1950, inasmuch as this increase was caused by the low flows occurring at Mile 44.2 between about 6 and 9 p.m. The lower D.O. values at 1 a.m. were produced by the higher flows around 10 p.m. The difference in the rate of travel of translatory waves and of the water initially composing them is clearly brought out here.

Reaeration in a short reach of a steep stream, the upper Watauga, is very rapid, as brought out in Figure 24. In the reach observed the slope is about 11 feet per mile. During the observation period in October 1949 the river flow was quite steady near 1000 cfs. The following tabulation shows the rapid rate of reaeration, and also brings out the increase in rate during daylight hours, due to the addition of oxygen by algae. Even though the D.O. concentration at the lower end of the reach was fairly high, with water at 12.0°C, there was still a deficit below saturation of approximately 14 percent.

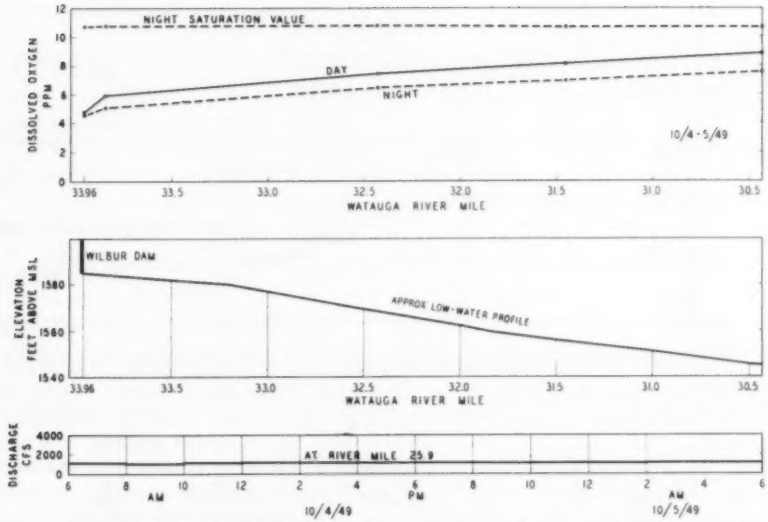


VARIATION IN REAERATION DURING 24-HOUR STEADY FLOW
HOLSTON RIVER - OCTOBER 1949

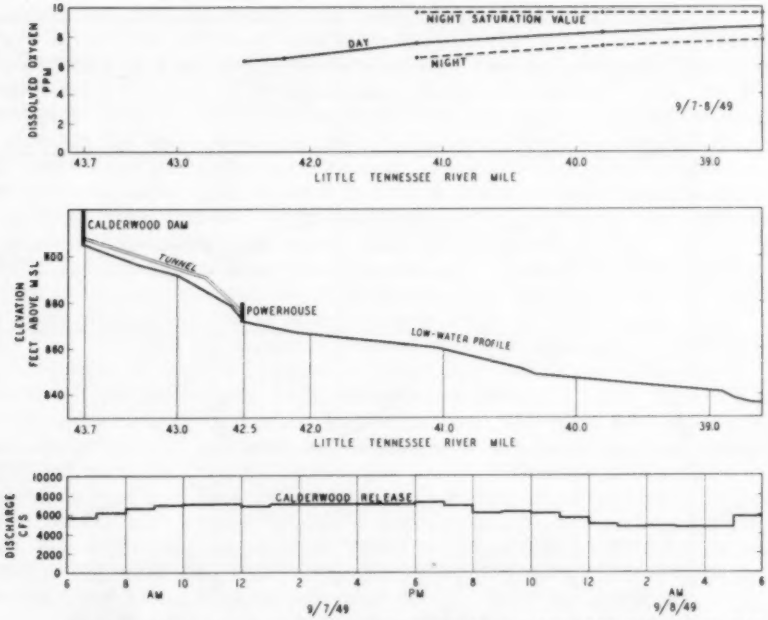


VARIATION IN REAERATION DURING 24-HOUR UNSTEADY FLOW
HOLSTON RIVER - AUGUST 1950

FIGURE 23



REAERATION IN WATAUGA RIVER BELOW WILBUR DAM - OCTOBER 1949



REAERATION IN LITTLE TENNESSEE RIVER BELOW CALDERWOOD DAM - SEPT 1949

FIGURE 24

REAERATION IN UPPER WATAUGA RIVER

October 4-5, 1949

For River Flow of 1000 cfs

Location	Mile	Time of Water Travel Days	D.O. Daylight ppm	D.O. Darkness ppm	Reaeration Coefficient Daylight	Reaeration Coefficient Darkness
Below Wilbur	33.85		5.90	5.05		
		0.033			6.02	3.53
Above Siam	32.43		7.38	6.37		
		0.027			4.80	2.40
Siam Bridge	31.45		8.12	6.90		
		0.038			4.60	2.04
Near Dugan Mill	30.43		8.84	7.52		

These observations illustrate the rapid reaeration produced by a turbulent stream flowing at a velocity of 2.6 ft. per second in the upper reach, 2.2 in the middle reach, and 1.6 in the lower of the three reaches. Note the night reaeration coefficients are roughly proportional to these velocities.

Still higher reaeration coefficients have been observed on the Little Tennessee River below Calderwood powerhouse. The slope of the river here is not quite as steep as for the upper Watauga, being about 9 feet per mile through the reach studied, but the river is wide and shallow, even at the observed flows of 7000 cfs. The width varies between 600 and 1200 feet and the mean depth at 7000 cfs is on the order of 3.5 feet in the narrow sections and 1.5 feet in the wider reaches. Water velocities vary from 3.2 feet per second in the deeper reaches to 4.2 feet per second on the broad, shallow shoals.

REAERATION IN LOWER LITTLE TENNESSEE RIVER

September 7-8, 1949

For River Flow of 7000 cfs

Location	Mile	Time of Water Travel Days	D.O. in Daylight ppm	Reaeration Coefficient For Daylight
1400 ft. below Powerhouse	42.25		6.48	
		.019		9.7
Gaging Station	41.25		7.42	
		.020		11.9
	39.85		8.19	
		.022		9.4
	38.60		8.58	

Although these coefficients are very high, it is obvious to the eye that the shallow, turbulent, river is an ideal aerator. With such high coefficients a stream could leave a powerhouse with, say, 1 ppm of D.O. (deficit of 8.6 ppm at 18°C) and become reaerated to within 1 ppm of saturation within about 2-1/2 hours flow time, or in a distance of 6.3 miles at 3.7 feet per second.

ACKNOWLEDGMENTS

Since the data presented herein cover a span of some 20 years and portions of the work of several Divisions of TVA, it is impossible to acknowledge the contributions of every individual. However, the contributions of Mr. F. W. Kittrell, formerly Chief, Stream Sanitation Section, and of Mr. A. S. Fry, Chief, Hydraulic Data Branch, exceed all others. Mr. G. R. Scott also deserves recognition for some of the earlier data.

The paper was written under the general direction of Dr. F. E. Gartrell, Assistant Director of Health, and of Mr. C. M. Davidson, Chief, Environmental Hygiene Branch. Special recognition is due Mr. R. A. Buckingham, Public Health Engineer, Stream Pollution Control Section, for supervision of the preparation of the Figures included in this paper.

The author is indebted to Mr. F. W. Kittrell and to Mr. Thomas M. Riddick for reviewing the manuscript and for many helpful suggestions.

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SLUDGE INCINERATION

Mark B. Owen,[1] M. ASCE
(Proc. Paper 1172)

SYNOPSIS

Sewage sludge may be classified as a low rank fuel. In fuel terminology, sewage solids, fresh or digested, contain higher fractions of volatile combustible matter, and less fixed carbon than any of the coals, lignite or peat. Consequently, sludge burns with much flame and appreciable heat.

The fundamentals of the combustion of coal, and the basic elements of furnace design required for optimum combustion, are applicable to the burning of sludge. These principles are incorporated in the multiple hearth furnace, resulting in a system which induces the practically complete combustion of sludge.

The design and operation of a multiple hearth furnace is discussed, and thermal calculations presented for preparing a heat balance applicable thereto.

GENERAL

Between the years 1891 and 1932 there were few publicized attempts made to burn sewage sludge, either as sludge alone or in combination with other wastes or combustible materials. Efforts to incinerate sludge with coke, garbage, rubbish and other materials were of laboratory proportions, pilot plant size or shortlived full scale tests that apparently offered too little promise of providing a practical combustion disposal system.

Apparently the first effective and practical work in burning sludge was that carried out in the few years prior to 1935. The first full scale sludge incinerator, a multiple hearth furnace, was put in operation in Dearborn, Michigan in February, 1935. Since that time many municipalities have selected incineration as the method of final sludge disposal.

Note: Discussion open until July 1, 1957. Paper 1172 is part of the copyrighted Journal of the Sanitary Engineering Division of the American Society of Civil Engineers, Vol. 83, No. SA 1, February, 1957.

1. Vice-Pres., Nichols Eng. & Research Corp., New York, N. Y.

There is no known practical method today that so nearly approaches the ultimate in waste solids reduction as incineration.

The Character of Municipal Wastes

The two common organic wastes produced by man are garbage and sewage. During the course of normal living, man will excrete about 0.2 of a pound of dry solids per day; and, in a similar period will discard, as waste from the preparation of food, about 0.12 of a pound of moisture-free garbage.

Garbage, as normally collected for disposal by incineration, is usually mixed with rubbish. In this condition it is ready for discharge into an incinerator.

Sewage solids, however, are accompanied and transported by an enormous volume of water, of which they represent about one-tenth of one percent. Sludge disposal must therefore be preceded by comprehensive treatment of sewage to recover the solids.

When sludge digestion is used in the system of sewage treatment, the designing engineer is concerned with the quantity of volatile matter in the sludge. In digestion, chemical reactions take place producing gases and water, thereby effecting a reduction of solids by a slow "wet combustion" process.

In sanitary engineering, volatile matter is commonly thought of as the portion of sewage solids lost on ignition. In other words it might be termed the combustible portion of the sludge. However, it should be noted here that the solids lost on ignition are not all organic solids, sometimes referred to as putrescible or humus solids. There are organic salts present in all sewage solids, such as carbonates, that decompose under the heat[2] used in this test.

In other engineering fields the combustible portion of solids such as coals, is thought of as fixed carbon and volatile combustible matter. Similarly, the volatile matter of sewage may be described in terms of fixed carbon and volatile combustible matter.

While sludge represents the major part of solids disposal, there are other sewage solids that frequently pose a difficult problem, such as grits, screenings, skimmings and grease. Where sludge incineration is available these solids are easily reduced to ash in the furnace with, or separate from the sludge.

Because of the many methods of treating grit, the volatile solids content varies widely. At some plants the volatiles average 10%, while at others, it exceeds 35% at times.

The combustible content of the dry solids in screenings will ordinarily average about 85% on a dry basis, and vary from 70 to 90 percent.

Skimmings and grease may not contain more than 35% moisture and at times will average 90% combustible matter in the dry solids.

The composition of some municipal wastes, and, comparisons of wastes with low rank fuels and other combustible materials, are shown in Table I.

One may wonder at the relatively high heat value of fresh sludge in comparison to some other materials listed; and, especially the low value of

2. "Analysis of Water and Sewage," by Theroux, Eldridge and Mallman, McGraw-Hill Book Company, Inc., New York, N. Y., 1943, p. 181.

TABLE I

Combustible Matter and Heating Values

of Municipal Wastes and Low Rank Fuels

Average B.t.u. per pound

Moisture-free basis

Item	Combustible %	Ash %	B.t.u.
Grease & scum	88.5	11.5	16,750
Lignite	89.0	11.0	10,850
Fresh sewage solids	74.0	26.0	10,285
Fine screenings	86.4	13.6	8,990
Wood	89.5	10.5	8,675
Peat	86.0	14.0	8,275
Ground garbage	84.8	15.2	8,245
Rags	97.5	2.5	8,050
Digested sewage & garbage solids	49.6	50.4	8,020
Newsprint	91.8	8.2	7,825
Rubbish, less tins and glass	89.0	11.0	5,900
Digested sludge	59.6	40.4	5,290
Grit	33.2	69.8	4,000

7,010 B.t.u. per lb. dry solids, shown in Table IV. The latter sludge was that from a chemical precipitation process. It is not unlikely that the wide spread in the calorific values of fresh and digested sludges is due to ether-soluble solids in the former, such as grease, that are not present in solids after digestion.

Municipal Wastes as Fuels

Fuel is basically cellulose containing the radiant energy of the sun stored up by the plant. The fuel in sludge is derived from living organisms originating in plant life and is organic matter that has been subjected to the metabolism of the human body, and, later, may or may not have undergone additional degradation by anaerobic digestion.

A fuel, to be of value, must be fairly easily ignited, burn freely and have a reasonably high calorific value. A fuel burning in air produces heat and will contain the energy necessary to assist in bringing about its own reduction to constituent elements.

The heating value of fuels is provided by their contained carbon and hydrogen fractions. One pound of carbon, burned to carbon dioxide has a heat value of 14,600 B.t.u. per pound; one pound of hydrogen (H_2) has a heat value of 62,000 B.t.u. per pound. Consequently any significant change in the carbon and hydrogen contents of the solids will materially raise or lower the calorific value of the sludge.

The proportions of combustible matter, ash and moisture in a solid fuel constitute an approximate, or proximate analysis. In the proximate analysis, fixed carbon is that portion of the combustible content of a fuel remaining after the volatile matter has been distilled off; volatile matter consists of hydrocarbons which pass into a gaseous state before igniting.

Fuels high in fixed carbon and low in volatile combustible matter burn with little flame.

Peats and lignites contain relatively high volatile components and burn with much flame.

Sewage solids are high in volatiles and quite low in fixed carbon, and burn with much yellow flame and with very little blue (fixed carbon) flame.

Table I-a shows some typical analyses of sludges and garbage.

TABLE I-a

Proximate Analyses

(Moisture-free)

Source or Plant	Date of Sample	Vol. Matter %	Fixed Carbon %	Ash %	Material
Piqua, Ohio	Jan.1941	76.6	17.0	16.4	Fresh sludge
Marion, Ind.	Oct.1947	60.0	4.6	35.4	Fresh sludge
Marion, Ind.	Oct.1947	48.8	2.9	48.3	Dig. sludge
Williamsport, Pa.	Jul.1955	54.5	5.2	40.3	Dig. sludge
Indianapolis, Ind.	Jul.1947	72.8	16.2	11.0	Garbage

Of interest are the above analyses converted to an ash-and moisture-free basis shown in Table II.

TABLE II

Proximate Analyses

(Ash-and Moisture-free Basis)

Source or Plant	Date of Sample	Vol. Matter %	Fixed Carbon %	Material
Piqua,Ohio	Jan.1941	91.7	8.3	Fresh Sludge
Marion,Ind.	Oct.1947	92.8	7.2	Fresh Sludge
Marion,Ind.	Oct.1947	94.3	5.7	Dig. Sludge
Williamsport,Pa.	Jul.1955	91.3	8.7	Dig. Sludge
Indianapolis,Ind.	Jul.1947	81.8	18.2	Garbage

Ultimate analyses, as distinguished from proximate analyses, are more complete and useful in that they provide the exact percentages of the component elements present in the solids. The important elements in combustion are carbon, hydrogen, oxygen and nitrogen; which when known provide an accurate basis for calculating the quantity of air needed for complete combustion of a fuel, and the quantity of resultant gases such combustion will produce.

Typical ultimate analyses of three wastes are given in Table III.

TABLE III

Ultimate Analyses

(Ash-and Moisture-free Basis)

Per cent

	C	H	O	N
Garbage	52.7	6.1	37.5	3.7
Fresh Sludge	59.8	8.5	27.5	4.2
Digested Sludge	54.9	7.6	29.6	7.9

While the chemical composition of residential sewage remains fairly constant, that of industrial wastes may vary quite widely. For instance, grease contributed by industry may at times raise the carbon and hydrogen percentages to as high as 64% and 12% respectively.

Calorific Values of Wastes

The heating value of fuels and wastes may be given in terms of British

thermal units (B.t.u.) per pound of waste "as received;" on a "moisture-free" basis; or, on an "ash-and moisture-free" basis.

Many conditions and factors contribute to great variations in the moisture content of waste materials, resulting in widely fluctuating heat values on an "as received" basis. Therefore, engineers frequently state the heat value of refuse and sludge on a moisture-free, or dry solids basis.

From week to week in any one plant, fresh and digested sludges may vary greatly in the percentage of volatile and mineral matter in the dry solids; but, in the ultimate analyses of the volatile solids of such sludges there will be a rather constant percentage of carbon, hydrogen, oxygen and nitrogen. When concerned with combustion calculations it seems logical to think of sludge solids in terms of the combustible content (ash-and moisture-free) rather than total dry solids, or, moisture-free.

If the ultimate analysis of a fuel is known, an approximate determination of the heat value can be made by use of the Dulong formula, which is:

$$Q = 14{,}600C + 62{,}000\left(H - \frac{O}{8}\right)$$

in which Q = the heat value, in B.t.u. per pound;
C = per cent of carbon in fuel;
H = per cent of hydrogen in fuel;
O = per cent of oxygen in fuel.

The result is the heat value per pound of fuel.

Applied to some coals this formula gives quite accurate values, but for sludges the values differ so much from those obtained by calorimeter as to make its application in sludge incineration impractical. The erratic results appear to be due to certain assumptions in the formula not applicable to sludge. The last term of the formula indicates all of the hydrogen and oxygen are combined in water. Actually there must be some free oxygen in all sludges and a considerable percentage of oxygen must be combined with nitrogen in organic nitrates.

The only reliable heating value for sludge is that determined experimentally in a calorimeter.

Using Dulong's formula, the digested sludge in Table III would contain 10,440 B.t.u. per lb. of combustible. By calorimeter the sludge actually had a heat value of only 8,980 B.t.u. per lb. of combustible.

In Table IV are given the calorific value of some fresh and digested sludges from eight different sewage treatment plants. All were made by calorimeter tests.

As might be expected, the presence of grease in sludge has a significant effect on the heating value. For example, one sample containing about 44% chloroform extract produced 16,957 B.t.u. per pound of combustibles; another, containing approximately 18.5% grease contained 12,200 B.t.u. per pound of combustibles.

The lowest rank fuel of the coals is "brown coal" or lignite. As mined, these coals may contain up to 40% moisture; and on a moisture-and ash-free basis have a heating value from 10,000 to 13,000 B.t.u per pound. It will be seen that as to its heat value, sludge is not unlike a low-rank fuel.

TABLE IV

Calorific Value of Sludges

B.t.u. per pound

Plant	Type of Sludge	Dry Solids	Combustible Solids
CS	Digested	5,975	12,480
DB	Digested	5,830	10,750
PE	Digested	5,290	8,980
AA	Digested	4,980	9,500
D	Fresh	9,485	13,855
DT	Fresh	10,285	13,905
AS	Fresh	9,125	11,415
MS	Fresh	7,010	10,155

Processing Sludge for Incineration

Sludge as delivered to an incinerator is generally in the form of filter cake produced by vacuum filtration of liquid sludge. Prior to filtration the sludge is "conditioned" with chemicals, such as calcium oxide, ferric chloride or other compounds used in combination or singly, depending upon the type of sludge being treated. The resultant filter cake may contain from 60% to 83% moisture.

In the sewage treatment plants at Ashland and Piqua, Ohio, primary sludges averaging about 87% moisture are conveyed directly from the sedimentation tanks to the incinerator without prior processing. No chemicals are added and no partial dewatering by filtration is practiced. Both of these plants were constructed in 1939.

While the chemicals used as an aid in filtering make possible the production of sludges as low in moisture as 65%, they also increase the mineral content, which decreases the per cent of combustible matter in the filter cake conveyed to a furnace.

The effect of conditioning chemicals on the fuel value of a sludge is illustrated by the following data[3] and related calculations:

3. Cleveland Southerly Sewage Treatment Report for 1954.

Digested sludge --	
Volatile solids	46.4%
Ash	54.6%
Chemicals, per cent of dry solids --	
Lime (90.5%CaO)	19.0%
CaO	17.2%
$FeCl_3$	5.54%
Vacuum filter cake --	
Moisture	73.1%

One hundred pounds of dry sewage solids treated in accordance with the above data, produce a mixture as follows:

Sewage volatiles	46.4 lb.
Sewage ash	53.6 lb.
$FeCl_3$	5.54 lb.
CaO	17.2 lb.
Lime inert	1.8 lb.
Total	124.54 lb.

As a fuel, the above dry solids are 37.2% combustible and 63.8% ash. In a filter cake containing 73.1% moisture the "as received" analysis would read --

Combustible	12.5%
Ash	14.4%
Moisture	73.1%
Total	100.0%

The foregoing calculations consider the chemicals added as ash. Theoretically the calcium oxide and ferric chloride in liquid sludge could react to form calcium carbonate and ferric hydroxide. Under optimum conditions one pound of CaO will produce about 1.78 lb. of $CaCO_3$; and, one pound of $FeCl_3$ will produce about 0.66 lb. of $Fe(OH)_3$.

If the above reactions occurred, the wet sludge leaving a vacuum filter at 73.1% moisture would have the following analysis:

Sewage combustibles	46.4 lb.
Sewage ash	53.6 lb.
$CaCO_3$	30.6 lb.
$Fe(OH)_3$	3.7 lb.
Lime inert	1.8 lb.
Moisture	369.8 lb.
Total	505.9 lb.

The filter cake, as received, is now 9.2% combustible; 17.7% ash; and, 73.1% moisture.

Again assuming optimum conditions of time and temperature in a furnace, the calcium carbonate and ferric hydroxide will dissociate in accordance with the following equations:

$$CaCO_3 + \text{heat} = CaO + CO_2$$
$$2Fe(OH)_3 + \text{heat} = Fe_2O_3 + 3\ H_2O$$

The heat required to produce the above reactions is equal to 958 B.t.u. per lb. of $CaCO_3$, and 511 B.t.u. per lb. of $Fe(OH)_3$, dissociated.

It is quite unlikely that calcium carbonate and ferric hydrate are always formed as theorized. It is still more unlikely that complete dissociation of such compounds would take place in an incinerator due to insufficient time and temperature. Practically, for incineration purposes, it is sufficient to consider the volatiles of sewage as combustible matter, and the added chemicals as ash.

The Combustion Process

Combustion is a rapid chemical reaction of oxygen and fuel producing light and liberating appreciable quantities of heat. In plain words, combustion is a burning process. The combustion process starts when the temperature of the fuel is raised to the ignition temperature, which ". . . . is that temperature at which the heat which is liberated by the union of the fuel with oxygen is evolved faster than it is conducted away. Then the fuel becomes hotter, the union proceeds more rapidly and this in turn heats the fuel and the immediate surroundings faster, until incandescence (flames) occurs. Oxidation—the slow union of the oxygen with a substance—may occur at any temperature. But combustion—the rapid union of oxygen with a substance—cannot occur below the ignition temperature. After the ignition temperature has once been attained (the fire "kindled" or "started") by a small portion of the fuel, the combustion will then proceed automatically. The heat released by the combustion of one small portion of the substance will heat other portions and so on until the entire mass is burning."[4]

The combustible elements of sludge and other fuels, are carbon, hydrogen and sulphur; which, when completely burned with oxygen form compounds called "products of combustion."

The products of complete combustion of substances like coal and sludge are carbon dioxide and water. Since oxygen required for combustion is supplied by air, the combustion products also contain a large amount of nitrogen. Sludges like coal, contain small quantities of sulphur which burn mainly to sulphur dioxide. These products are also known as "stack gas," "flue gas," and "waste gas." In addition to the combustible elements, sludge contains inert substances like oxygen, nitrogen, ash and moisture that do not react with the oxygen that is provided for the combustion reactions, but as will be shown later, contribute to weight and volume of flue gas.

Table V provides data useful in combustion computations.

Combustion takes place in accordance with the following simple chemical reactions:

(1) $C + O_2 = CO_2$

(2) $2H_2 + O_2 = 2H_2O$

(3) $S + O_2 = SO_2$

(4) $2CO + O_2 = 2CO_2$

(5) $CH_4 + 2O_2 = CO_2 + 2H_2O$

The above equations not only show what substances enter into the reactions, but also the proportions in which they participate. Thus, $C + C_2 = CO_2$ means that 12 parts by weight (pounds, grams, tons, etc.) of carbon and 32 parts by weight of oxygen combine to form 44 parts by weight of carbon

4. Terrell Croft, "Practical Heat," McGraw-Hill Co., p. 439, 1939.

TABLE V

Properties of Components of Combustion

Based on one pound of Material

	Molecular Symbol	Atomic Weight	Mol. wt.	Weight lb.per cu.ft.	Volume** cu.ft. per lb.
Carbon	C*	12.005			
Hydrogen	H_2	1.008	2.015	0.0053	187.723
Oxygen	O_2	16.000	32.000	0.0846	11.819
Sulphur	S_2	32.07	64.14		
Nitrogen	N_2	14.01	28.02	0.0744	13.443
Carbon Dioxide	CO_2		44.01	0.1170	8.548
Carbon Monoxide	CO		28.01	0.0740	13.506
Methane	CH_4		16.03	0.0424	23.565
Sulphur Dioxide	SO_2		64.07	0.1733	5.770
Air			28.94	0.0766	13.063
Water Vapor	H_2O		18.015	0.0476	21.017

* Atomic symbol

** All gas volumes at 60°F. and 30 in. Hg. dry.
Air is principally 23.2% oxygen and 76.8% nitrogen, by weight.

dioxide. This reaction may be termed perfect combustion of carbon. If insufficient oxygen is present, combustion proceeds as in Equation (4) which is imperfect burning of carbon. When carbon burns to carbon dioxide it releases 14,600 B.t.u. per lb. of carbon; but, when it burns to carbon monoxide only 4,350 B.t.u. of heat are released per lb. of carbon. Similarly, $2H_2 + O_2 = 2H_2O$, implies that 4 parts of hydrogen and 32 parts of oxygen, both by weight, combine to form 36 parts by weight, of water.

In equation (1) above, the weight ratio of oxygen to carbon is, $32 \div 12 = 2.667$; in equation (2), the weight ratio of oxygen to hydrogen is, $32 \div 4 = 8$. Therefore, 1 lb. of carbon will burn completely with 2.667 lb. of oxygen to form 3.667 lb. of carbon dioxide; and, 1 lb. of hydrogen requires 8 lb. of oxygen to burn completely, forming 9 lb. of water. The data in Table VI are based on these fundamentals.

TABLE VI

Products of Combustion

and Air Requirements*

lb. per lb. of Combustible

	Required for Combustion			Products of Combustion		
	O_2	N_2	Air	CO_2	H_2O	N_2
Carbon	2.667	8.873	11.540	3.667		8.873
Hydrogen	7.939	26.414	34.353		8.939	26.414
Carbon Monoxide	0.571	1.900	2.471	1.571		1.900
Sulphur	1.0	3.29	4.29	SO_2=2.0		
Methane	3.992	13.282	17.274	2.745	2.248	13.282

* Based on theoretical quantity of air.

Theoretical air is the minimum quantity of air to burn completely all carbon to CO_2, all hydrogen to H_2O, and all sulphur to SO_2.

The amount of air actually needed to accomplish practical and approximate complete combustion is considerably larger than the theoretical quantity. To assure complete combustion whereby every oxygen molecule comes into intimate contact with each carbon molecule, an excess number of oxygen molecules over the theoretical quantity is necessary. Furthermore, these intimate contacts must be maintained a sufficient length of time to complete the chemical reactions.

The amount of excess air required varies with the type of burning equipment, the character of the material to be burned; and, in the case of incineration, by the disposition of the stack gases. The amount of excess air for best incineration must be determined by trial for each individual installation.

While the fundamentals of burning fuels like coal are applicable to the combustion of sewage sludge, it is important to remember that commercial fuel is burned to produce heat energy—wastes are burned to destroy them. A boiler furnace, for instance, is a productive unit in which the maximum quantity of stream per minimum quantity of fuel consumed is the economic goal. Excess air carries useful heat away from the boiler, up the stack; therefore, its use is carefully regulated.

Excess air in a sludge furnace, operating with extraneous fuel, absorbs heat that may be needed to support combustion; and, carries it out the chimney with the waste gases. If the sludge furnace is operating without fuel, excess air lowers the temperature of combustion and exhaust gases.

The specific heat of a gas at a single temperature is the B.t.u. required to raise 1 lb. of the gas 1° Fahrenheit. In order to calculate flame temperatures and the quantity of heat lost in flue gases it is necessary to know the mean specific heat of gases over the range of temperatures in question. Thus the heat required to raise a gas to any temperature is the product of its weight in pounds, the temperature rise in degrees Fahrenheit, and the mean specific heat of the gas for the temperature gauge involved, or, $Q = WC(t = T)$, wherein,

Q = total heat required, in B.t.u.
W = weight of gases, in lb.
C = mean specific heat of gases
t = initial temperature of gases, °F.
T = final temperature of gases, °F.,

TABLE VII

Mean Specific Heats

(900°F.--60°F.)

B.t.u. per lb. of gas

Carbon Dioxide	0.244
Water Vapor	0.472
Nitrogen	0.256
Air	0.250

Flue losses due to water vapor may be computed by four different methods:[5]

1. Water is assumed in the gaseous state over the whole temperature range, and the latent heat taken at the boiling point.
2. Water is assumed to be vapor above 212°F. and liquid between 212° F. and room temperature.

5. George B. Shawn, A.G.A. Monthly, Oct. 1938.

3. Water is considered as liquid below the dew point and as vapor above.
4. Water is considered as vapor above room temperature with condensation occurring at room temperature.

While the third method most nearly approximates the true conditions, the fourth involves less computation and gives results very close to the third method.

In the computations shown later herein, water vapor losses are determined in accordance with the assumption in the fourth method; and, the latent heat of water at 60°F. is taken at 1060 B.t.u. per pound.

The theoretical flame temperature that a fuel will produce is attained when all of the heating value of the fuel goes to raising the temperature of the ingredients. By the definition of specific heat already given it is possible to calculate the theoretical temperature of flame and the theoretical temperature of combustion reached in burning sludge and other fuels. Since $Q = WC(t-T)$,

$$T = \frac{Q}{WC} + t$$

The theoretical temperature of combustion of carbon with the theoretical quantity of air at 60°F. is—

$$T = \frac{14,600}{3.667 \times 0.29} + 60 = 13,760°F.$$

When burned with 100% excess air, the theoretical temperature is—

$$\frac{14,600}{12.54 \times 0.29} + 60 = 4,070°F.$$

Thus does excess air affect the temperature of combustion.

In the above equation, 12.54 equals the products of combustion (Table VI), in pounds; and, 0.29 is the approximate mean specific heat per pound of gas, between 60°F. and 4000°F. The product, (12.54 x 0.29), is the heat, in B.t.u. required to raise 1 lb. of the gases 1° Fahrenheit.

This formula also provides a way of calculating the effect of preheated air on the final temperature of combustion. It obviously requires less heat to raise the temperature of a gas from 350°F. than from 60°F. Thus, if t = 350°F., the temperature reached in the last equation would theoretically be about 4,220°F.

The fuel burned in a furnace provides a certain quantity of heat of which a considerable amount is absorbed by the furnace and is lost by radiation from the structure; a larger portion is lost in the flue gases discharged through the chimney to atmosphere; a smaller portion is carried away in the ash. The difference between the heat evolved and the heat lost is heat available, in the case of a boiler furnace, for producing steam. The net heat available for useful purposes is determined by means of a heat balance.

The Multiple Hearth Furnace

The multiple hearth furnace is a unique combustion device. Unlike all furnaces designed for the combustion of waste materials, commonly referred to as incinerators, this furnace employs no open burning grates. Therefore, all of the fundamentals of combustion of fuel on open grates are not applicable to the multiple hearth furnace.

The furnace described herein was conceived by Dr. J. B. F. Herreshoff in 1889 under the sponsorship of Dr. William H. Nichols, for the purpose of roasting pyrites for the manufacture of sulphuric acid. In the ensuing 67 years many improvements have been made, making it adaptable for use in many industries and for the drying or burning of sewage sludges, grits, grease, screenings and other sewage solids.

As presently designed the multiple hearth furnace consists of a circular steel shell surrounding a multiplicity of solid refractory hearths and a central rotating shaft to which rabble arms are attached. Since the operating capacity of these furnaces is related to the total area of the enclosed hearths, they are designed with various diameters and a varying number of hearths, usually between four and eleven.

Plate I shows, in cross section, a typical 7-hearth furnace, proportioned to burn approximately 4-1/2 tons of 75% moisture filter cake per hour.

Since this furnace may operate at temperatures up to 2000°F., the central shaft and rabble arms are effectively cooled by air supplied in regulated quantity and pressure from a blower discharging air into a housing at the bottom of the shaft.

The central shaft is an iron column cast in sections. The sections enclosed by the furnace have a tubular inner column called the "cold air tube." The annular space between the inner tube and the outer wall of the shaft exposed to furnace heat, serves as a passageway for hot air and is referred to as the "hot air compartment." Two or more rabble arms are attached to the shaft at each hearth with ample air passages provided from the "cold air tube" to the rabble arms. Each rabble arm is constructed with a central tube for the purpose of conducting the cold air to the extreme end of the rabble arm, thence back through an outer air space in the arm to the shaft and through passages opening into the hot air compartment from which it may be discharged to atmosphere or returned to the bottom hearth of the furnace as preheated air, for combustion purposes.

The vertical furnace shaft revolves upon hardened steel buttons set within a step bearing and is supported at the top by a simple bearing. The shaft is motor driven through means permitting adjustment of speeds from one revolution in two minutes to about three revolutions a minute as required.

Rabble arms and teeth are cast of chrome-nickel-iron. The arms are held in machined sockets of the shaft by alloy pins. Rabble teeth are cast with a dovetail button that loosely fits the dovetail groove along the underside of the rabble arm. A plate is cast as a part of each tooth so that when all teeth are in place, and plates touching each other, each tooth is automatically set at its correct angle upon the arm.

The hearths are constructed of high heat duty fire brick and special fire brick shapes. The upper, or No. 1 hearth in furnaces having an even number of hearths, has a central opening or port through which sludge passes to the second hearth. The upper hearth in this case is termed an in-feed hearth; and the second, or next lower, an out-feed hearth.

The top, or No. 1 hearth of furnaces having an odd number of hearths, such as shown in Plate No. I, is an out-feed hearth, and the next lower, or No. 2 is an in-feed hearth.

Out-feed hearths have ports, or drop-holes, around the periphery of the hearth, through which the sludge passes to the next lower, or in-feed hearth.

The central circular opening of the in-feed hearths are constructed to leave a large clear opening between the edge of the hearth and the wall of the shaft. The ports of the out-feed hearth are constructed to provide openings all around the hearth which permits of a well distributed supply of burning sludge to the next lower hearth and tend to regulate gas velocities.

From an out-hearth, the gases flow upward through the inner drop hole of the hearth above, and across the surface of that hearth cover to, and through the peripheral drop holes of the next out-hearth above, thence through and across the remaining hearths to the furnace gas outlet.

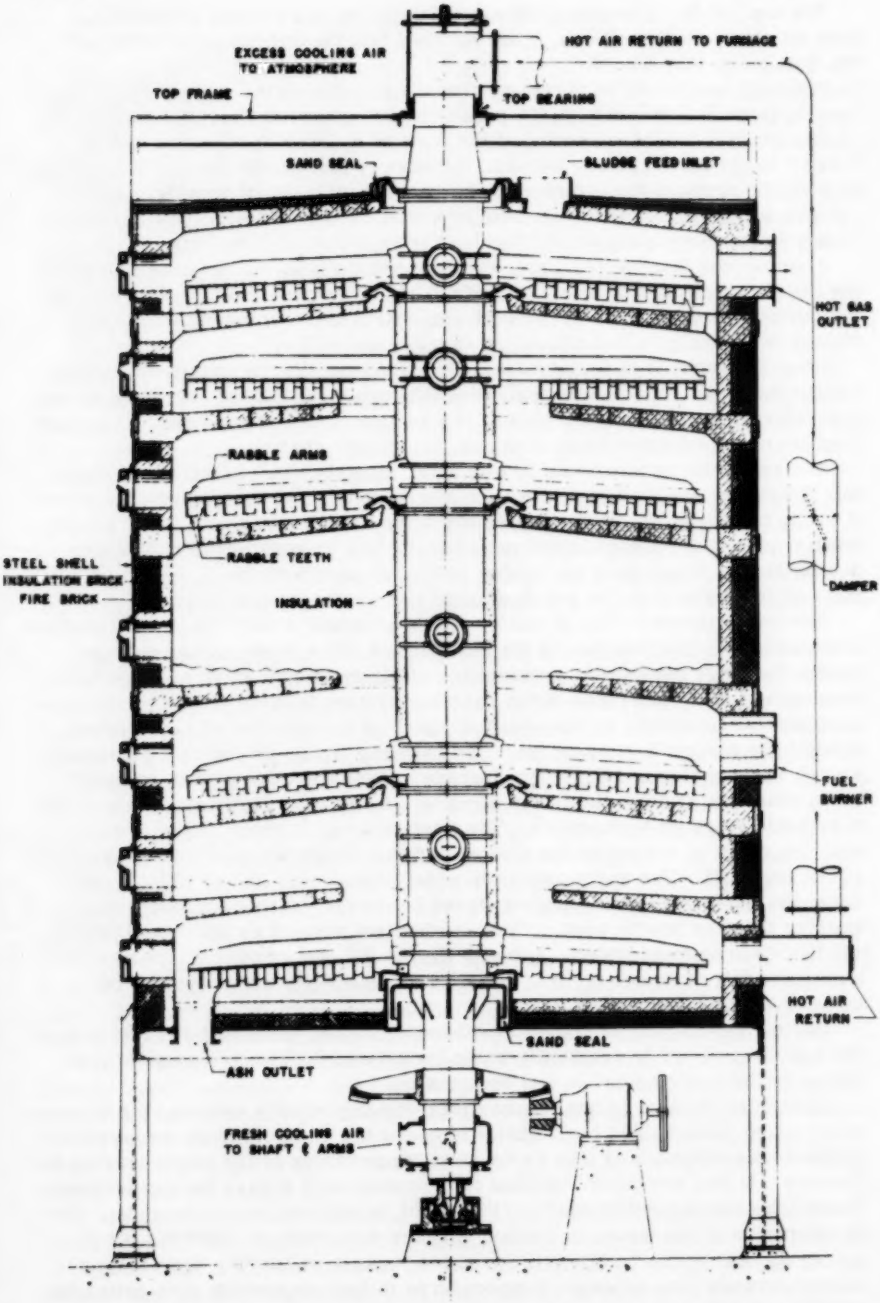
When the furnace is in operation, sludge enters the top hearth through a hopper equipped with counter-balanced flap gates. If the top hearth is an in-feed hearth, the feed hopper is near the periphery; if the top hearth is an out-feed hearth, the hopper is located near the center shaft.

The revolving rabble arms to which are attached "in" rabble teeth transmit the sludge across hearth No. 1 to the large central opening through which it drops to hearth No. 2. On hearth No. 2 the rabble arms with "out" rabble teeth transmit the sludge to the peripheral ports through which it drops to hearth No. 3. From here the sludge moves as on hearth No. 1 and so on through the furnace to the ash discharge port on the bottom hearth.

The small particle size of sludge solids presents a very large total surface area, which when enveloped in the moisture of filter cake, makes sewage sludge the most reluctantly combustible of all municipal wastes. This fact emphasizes the importance of the rabbling system in the multiple hearth furnace and the necessity of frequent turn-over of the fuel bed to accomplish practically complete combustion. The rabbling action produces a maximum sludge surface exposed to the hot furnace gases, and a long time, or short time, detention of material in the furnace, as desired. Rabbling forms spiral ridges of sludge on each hearth. The surface area of these ridges varies with the angle of repose of the sludge, and this angle varies with the moisture of the material. The angle may vary widely—say from 30° to 60°. In any case, the surface area of sludge exposed to the hot gases is considerably greater than the hearth area. Thus an effective area of as much as 130% of the hearth area is provided. Actually the sludge-gas contact is greater still, due to the fall of sludge from in-hearth and out-hearth ports through the counter-current flow of hot gases.

Drying and burning of sludge is enhanced further since in its travel across the hearths, sludge is constantly being turned and broken into smaller particles by the rabbling action and combustion.

In burning sludge, or any similar fuel, the ingredients entering the furnace must all be raised from their initial temperature to the ignition temperature of the combustibles, and then to the final temperature of the gases leaving the furnace. In this operation the final temperature will always be considerably lower than the highest temperature reached in the combustion process. The temperature of the gases in a boiler furnace may average 2000°F., but by giving up heat to the boiler, will leave the furnace at 500°F. Similarly, a sludge furnace may generate temperatures in the combustion zone averaging 1600°F., and the gases in giving up heat to the incoming sludge, leave the furnace at 500°F. to 900°F.



TYPICAL SECTION OF NICHOLS HERRESHOFF SLUDGE FURNACE

TABLE VIII

Operating Temperatures
of some multiple hearth furnaces
maximum, minimum & average
values are representative of actual operations
of from 8 hr. to 24 hr. each

Plant	Gas Outlet	Hearths No.2	No.3	No.4	No.6
Barberton, Ohio					
Max.	960	1620		1120	450
Min.	740	1270		1320	600
Av.	880	1500		1250	525
	930	1600		1210	480
	780	1340		1400	540
	860	1500		1250	500
Toronto, Ontario					
Max.	530	810	970	1480	1160
Min.	495	760	855	1330	1055
Av.	510	785	910	1405	1105
	595	855	935	1575	990
	470	785	900	1570	1360
	530	820	915	1570	1175
Akron, Ohio					No.5
Max.	810	1090	1390	1140	725
Min.	570	750	1310	1080	670
Av.	730	910	1340	1140	710
	880	1170	1585	1380	965
	725	830	1500	1315	900
	795	975	1545	1350	940
Ann Arbor, Mich.					
Max.	625	980	1050	1400	1210
Min.	500	870	890	1250	910
Av.	550	930	950	1310	960
	660	1000	1080	1460	1180
	610	980	1050	1340	1150
	635	995	1070	1415	1160
Williamsport, Pa.					
Max.	620	880	1070	1470	1680
Min.	520	740	860	1360	1510
Av.	585	810	990	1405	1570

Table No. VIII shows some typical temperatures throughout multiple hearth furnaces during the operation of various installations.

Thermal Calculations

A heat balance for a multiple hearth furnace comprises the following quantities:

1. Heat absorbed by—
   a. Latent heat in free moisture and moisture of combustion.
   b. Sensible heat in gases of combustion and excess air.
   c. Ash.
   d. Radiation.
   e. Shaft cooling air.
2. Heat evolved from—
   a. Combustibles in
      x. solids
      y. fuel.

In a heat balance, the total heat absorbed must equal the total heat evolved.

Basic data for thermal calculations:

Analysis of sludge combustibles

C	59.8%
H_2	8.5%
O_2	27.5%
N_2	4.2%
	100.0%

Calorific value: Combustible, ash-and moisture-free, 11,000 B.t.u. per pound.

Analysis of fuel oil--approximate

C	85.0%
H	12.0%
S	1.5%
	100.0%

Calorific value of fuel:

148,000 B.t.u. per gallon

19,000 B.t.u. per pound

Temperatures -- °F.

Atmosphere	60
Materials	60
Gases leaving furnace	900
Ash leaving furnace	700

Mean Specific Heats -- (900°F - 60°F)

CO_2	0.244
H_2O	0.472
N_2	0.256
Air	0.250

Ash -- (700°F - 60°F) = 0.20

Latent heat of water at 60°F -- 1060 B.t.u.

Products of Combustion:

Sewage combustibles with 50% excess air

Per pound of combustible

CO_2	2.19
H_2O	0.77
N_2	6.67
Ex. Air	4.31
Total	13.94

Fuel oil with 25% excess air:

Per pound of oil

CO_2	3.12
H_2O	1.08
SO_2	0.02
N_2	10.76
Air	3.50
Total	18.48

Heat content of gases

Sensible heat in 1 lb. of sewage combustibles at 900°F. over 60°F.

2.19 lb.	CO_2	x	205	=	448 B.t.u.
0.77 lb.	H_2O	x	397	=	306 B.t.u.
6.67 lb.	N_2	x	215	=	1434 B.t.u.
4.31 lb.	Air	x	210	=	905 B.t.u.
Total				=	3093 B.t.u.

Latent heat at 60°F -- 0.77 x 1060 = 818 B.t.u.

Sensible heat in 1 lb. of fuel oil at 900°F. over 60°F.

3.12 lb.	CO_2	x	205	=	640 B.t.u.
1.08 lb.	H_2O	x	397	=	429 B.t.u.
0.02 lb.	SO_2	x	146	=	3 B.t.u.
10.76 lb.	N_2	x	215	=	2313 B.t.u.
3.50 lb.	Air	x	210	=	735 B.t.u.
Total				=	4120 B.t.u.

Latent heat at 60°F. -- 1.08 x 1060 = 1145 B.t.u.

Heat in shaft cooling air = 385,000 B.t.u. per hour

Radiation = 55,000 B.t.u. per hour

Sensible heat in ash = 128 B.t.u. per pound

Materials to burn, pounds per hour

Combustibles	350	=	17.5%
Ash	150	=	7.5%
Moisture	1,500	=	75.0%
Total	2,000	=	100.0%

Heat Balance

F = pounds of oil

Heat absorbed			
a.	Latent & sensible heat, combustible 350 x 3911	=	1,368,850
b.	Latent & sensible heat, moisture 1500 x 1457	=	2,185,550
c.	Latent & sensible heat, oil F x 5265	=	
d.	Sensible heat in ash 180 x 128	=	23,040
e.	Radiation	=	55,000
f.	Heat in shaft cooling air	=	385,000
	Total = 5265 F +		4,017,440
Heat evolved			
g.	From combustible 350 x 10,500	=	3,675,000
h.	From oil F x 19,000	=	
i.	From return shaft air	=	346,500
	Total = 19000 F +		4,021,500

The total heat evolved is approximately equal to the heat absorbed, and in this case, no fuel would be required to maintain combustion.

If the calorific value of the sewage combustible were 10,000 B.t.u. instead of 10,500 B.t.u. per pound, the heat absorbed would exceed the heat evolved by 170,940 B.t.u. Then 19,000 F—5,265 F would = 170,940 and F = 12.44 lb. of oil per hour. 12.44 ÷ 7.79 = 1.6 gal. oil per hour, required to maintain combustion.

The ultimate analysis of sewage combustible in the foregoing thermal calculations is of a fresh sludge from the Ashland, Ohio, sewage treatment plant. The calorific value of this sludge, determined by calorimeter, was actually 11,773 B.t.u. per pound of combustible.

Incineration of Sewage Solids Other Than Sludge

In sewage plants equipped with multiple hearth furnaces, all solids removed in the treatment process, such as grits, grease and screenings, may be burned with, or without, sludge. Separate feed openings in the furnace are desirable for grease and coarse screenings.

In the multiple hearth furnace at the Jones Island, Milwaukee, sewage treatment works, 50 to 60 tons of screenings and grits are burned daily. During an official 36-hour test operation the characteristics of the solids burned were as shown in Table IX.

TABLE IX

Composition of Materials Burned

Milwaukee Sewage Treatment Plant

Jones Island, June 8-9, 1953

36-hour test

	As received		Moisture	Dry Solids		B.t.u./lb. as rec'd
	lb.	%	%	Vol.	Ash	
Coarse screenings	13,209	8.45	66.4	74.8	25.2	
Fine screenings	34,775	22.30	54.7	80.2	19.8	
Grits	98,549	63.20	54.5	52.1	47.9	
Chaff	9,407	6.05	5.1	67.0	33.0	
Total	155,940	100.00				

The weighted average of the above mixture, as "fired," was as follows:

Combustibles	26.1%
Ash	18.4%
Moisture	52.5%
Total	100.0%

Calorific value of mixture, as fired - 6625 B.t.u./lb. Fuel oil consumed, after ignition of wastes - none. Average Furnace temperatures, °F., during test -

Gas outlet	1180
Hearth No. 2	1210
Hearth No. 3	1350
Hearth No. 4	1130
Hearth No. 5	1020
Shaft cooling air	495

Combustion of sludge, grease and grits in the multiple hearth furnaces at Detroit has been the practice for several years. Of the total quantity of wet materials burned, approximately 9.7% is grit; 1.0% is grease and scum; and 89.3% is sludge. In the year ending June 30, 1955, the tons of wet materials burned were as follows:

Grit	18,596
Grease and scum	1,946
Sludge	196,781
Total	217,323

Note: All of the foregoing Milwaukee data were taken from the official report of the Milwaukee Sewerage Commission Engineers, W. Wieneke, Wm. Landsiedel and H. M. Hiesig, June 15, 1953.

As a burning unit the multiple hearth furnace comprises four distinct zones in which the combustion of wet sludge is carried out to practical completion.

The upper hearths form a drying and cooling zone in which vaporization of some free moisture occurs, and, an appreciable cooling of exhaust gases takes place, all by transfer of heat from gas to sludge.

The intermediate hearths form the combustion chamber; a high temperature burning zone, in which all volatile gases and solids are burned. Combustion of the major portion of total fixed carbon takes place on the lowest hearth of the combustion zone.

The bottom hearth of the furnace is a cooling and air-preheating zone in which ash is cooled by giving up heat to the shaft cooling air which is returned to the furnace in this zone. These zones are always apparent in a furnace operating under design conditions.

In Table X are data collected during three 8-hour operating periods of a furnace in Bay City, Michigan.

During these periods of operation no extraneous fuel was needed to maintain combustion. The stack gases were free from smoke at all times. The Bay City furnace has six hearths, but is not equipped with a thermocouple on the sixth hearth.

The data in Table X indicate that in the upper hearths the temperature of the sludge varied but little during its retention and travel across the drying hearths to the combustion zone; and, that the temperature did not exceed 155°F.

Further, the moisture content of the sludge during its travel across the hearths to the high temperature zone did not fall below 41%, from a high of 64.5 percent. It appears that evaporation of the moisture was a factor in maintaining low sludge temperatures on the three upper hearths.

Further, based on the volume of stack gases produced, the loss of volatile matter was not significant.

Three years before the installation of the multiple hearth furnace in Dearborn, investigations and research on sludge drying and incineration were conducted by the Department of Sewage Research, New Jersey Agricultural Experiment Station, New Brunswick, N. J. In the summary of a paper[6] discussing one investigation, it was stated, "Distillation of volatile matters from sludge containing 75 percent moisture did not occur until 80 to 90 percent of this moisture had been driven off, regardless of the temperature. In drying operations with subsequent incineration, a moisture content of the sludge from 20 to 30 percent would probably prevent nearly all odor trouble and reduce heat required in the combustion step."

It is interesting to note the very appreciable drop in the waste gas temperatures while travelling from hearth No. 2 to the gas outlet. This indicates the gases closely sweep over the surface of the sludge giving up heat to the sludge while picking up moisture. Longtime observation also indicates that in travelling across the upper hearths wet sludge captures significant quantities of fly ash. There is sufficient evidence to say that the wetter the sludge feed to a multiple hearth furnace, the cleaner the exhaust gas.

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6. "Loss of Volatile Matter by Drying Sewage Sludge Before Incineration," W. Rudolfs and Wm. H. Baumgartner, Water Works and Sewerage, Vol. 79, 1932, p. 199.

TABLE X

Operating Data

Bay City, Michigan

Multiple hearth sludge furnace

February, 1955

	Hearth		Sludge	
Hearth No.	Gas Temp. °F	Temp. °F	H_2O %	Volatiles %
1	500	142	64.5	48.1
2	1020	151	63.6	51.1
3	1200	141	52.1	48.8
4	1350	flame	flame	flame
5	1050	flame	flame	flame
1	450	155	63.6	55.8
2	950	150	55.4	50.7
3	1120	150	54.9	46.6
4	1300	flame		
5	1000	flame		
1	450	95	62.8	57.4
2	700	147	56.2	53.5
3	820	144	41.2	53.5
4	1260	flame		
5	1350	flame		

Plates No. II and III show an in-discharge and an out-discharge hearth, taken during the erection of one of the multiple hearth furnaces in Detroit. These are presented as an aid in visualizing how the in-drop and out-drop holes force the gases to tranverse the entire surface of all hearths; and, at the same time produce the turbulence required for good mixing, by the splitting and turning action induced in the gas streams.

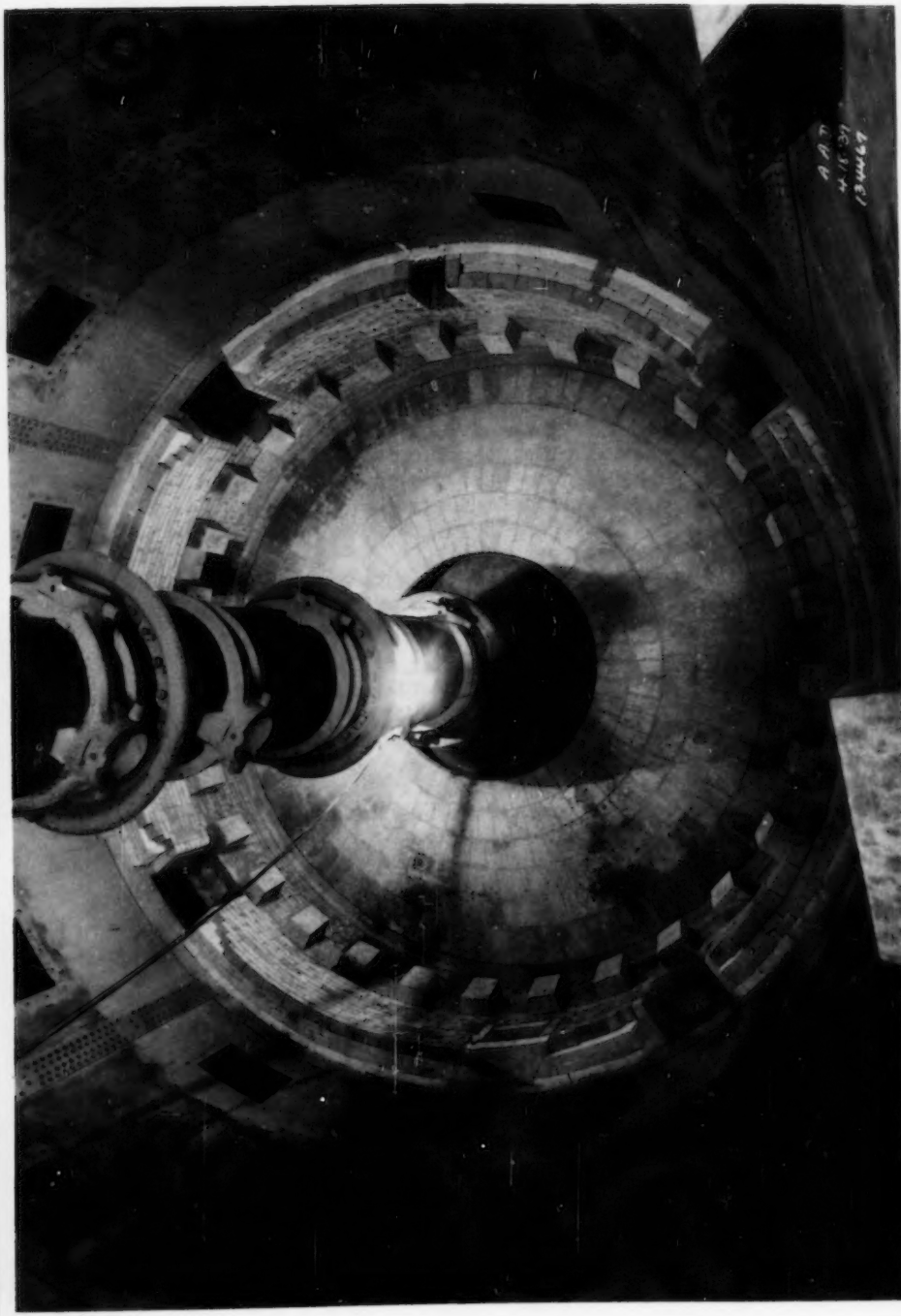
Years ago the United States Bureau of Mines conducted extensive tests and investigations concerning the combustion of coal on grates. These investigations established some important fundamentals applicable to the burning of sludge in a multiple hearth furnace:

1. Volatiles distilled off from a fuel bed are burned in the space above the fuel bed if secondary air is provided.
2. Distillation of volatile matter occurs in the presence of oxygen. It is possible that if oxygen is present in sufficient quantity at the time of distillation the heavy hydrocarbons will burn directly to products of complete combustion—CO_2 and H_2O.
3. Furnace gases are not of uniform composition; they tend to flow in stratified streams. The slower the gases move the greater the tendency to increase stratification; which, inhibits the air and combustible matter from burning, thereby causing smoke.
4. For best results the secondary air should be introduced as near to the fuel bed as practicable, and the air should be supplied in a large number of streams at high velocities.
5. The rapidity of burning combustible in the combustion space depends upon the quantity of oxygen intimately mixed with the combustible. The larger this quantity the faster the combustible burns.

The Bureau of Mines report[7] stated that, "mixing is an important factor in combustion," and that ". . . . . the air must be supplied as near to the surface of the fuel bed as practicable, and be thoroughly mixed with the combustible matter in order that the combustion may be completed in a short time and a small combustion space made effective."

In superposing hearths with in-drop and out-drop ports on alternate hearths the designers have provided a sludge furnace that practically meets the requirements for complete combustion.

7. Henry Kreisinger, C. E. Augustine and F. K. Ovitz, Bureau of Mines Tech. Pap. No. 135, 1917.



Paper 1173 SA 1

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Proceedings of the American Society of Civil Engineers

SLUDGE DIGESTION OR INCINERATION

Eugene R. Davis,[a] A.M. ASCE
(Proc. Paper 1173)

ABSTRACT

The factors determining the economics of digestion versus incineration are so dependent on local conditions that no general conclusion can be reached for all conditions. Each problem is specific in itself.

General

The digestion of sewage sludge represents a method of sludge conditioning which purpose is to make the sludge more acceptable for disposal while the incineration of sewage sludge constitutes a method of sludge disposal which has the final result of preventing accumulations of material. The basic functions, then, of digestion and incineration in the sewage treatment process are different in purpose.

Because certain sludge disposal methods will permit the processing of raw or digested sludges, the question to digest or not to digest is often raised. It would appear that the elimination of a conditioning unit would affect a certain economy with respect to fixed and operating costs. The difficulty, however, is that digestion has certain values other than the stabilization of sludge. These values may under certain conditions be of economic importance when the disposal method and other conditioning units of the process are considered. As the responsibility of the design engineer is to provide acceptable sludge disposal at the lowest possible cost, the use of digestion, where not required as a conditioning unit, is justifiable only when the cost of sludge disposal is reduced. The selection of any sludge disposal method is governed by the availability and the cost of disposal. Incineration regardless of geographical location is always available and from this standpoint is in competition with any other method. The design engineer has, therefore, the choice of utilizing incineration as a method of disposal for any sewage treatment

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plant under his consideration. This choice is usually resolved on the basis of the relative cost of incineration when compared with other possible methods of disposal.

Digestion

The digestion process has for the past few years and is at the present time under very active research work which has had very fruitful results. Morgan[1] and Torpey[2] have proposed high rate digestion processes in which the sludge is either dewatered before or after digestion. Morgan's system allows loading of volatile solids as high as 0.2 lb. per day per cubic foot and on this basis the volume of required digestion capacity is greatly reduced. As a result, this system has the economic advantage of decreasing the capital investment charges for providing digestion space. To this writer, it appears that this process will require trained supervision and due to the general lack of such supervision in small sewage treatment plants, the applicability in such cases is questionable.

As the evaluation of high rate digestion with regard to its affect on subsequent conditioning units, and the role which it will assume in sewage treatment processes have to the writer's knowledge not been fully determined, this paper will consider only standard methods of digestion.

Normal digestion practice is to digest the sludge in either a single space or two stage process. The capacities of digestion tanks are usually set by local departments of health with some reduction in size permitted where vacuum filtration is proposed. One such standard set by the joint committee[3] gives the following requirements:

Process	Heated Tank Cuft/cap
Primary	2-3
Primary tanks trickling filter	3-4
Activated Sludge	4-6

Under such requirements, the total cost of providing digestion capacity is a large one.

Depending on the method of disposal, no conditioning other than digestion may be required. However, in the majority of cases of sewage treatment, as practiced, digested sludge requires additional conditioning before disposal is possible. The digestion of sludge reduces the volatile solids content of sludge, the volume of solids to be handled, produces gas, and due to the reduction of putrescible matter is capable of producing a more acceptable sludge for disposal.

Incineration

The incineration of sewage sludge is usually accomplished in one of two types of incinerators, the multiple hearth or flash dryer. The advantage of incineration is that the final combustion product is chemically and bacteriologically stable, and from this standpoint presents no problem; but has

disadvantage that there is a resulting ash which requires disposal. Any type of sludge may be incinerated; liquid raw, dewatered raw, liquid digested, or dewatered digested. Incineration as normally practiced is preceded by vacuum filters on which raw or digested sludge is filtered. If raw sludge is filtered, the filtering process usually has been preceded with a thickening stage of treatment. Digested sludges usually are elutriated before filtering to reduce the required conditioning chemicals. The costly operational part of this disposal process is the vacuum filtration including the cost of chemicals for conditioning. For this reason, the incineration of liquid sludges with the elimination of the vacuum filtration process offers a special incentive for development. Piqua, Ohio[4] has burned liquid raw sludge on a multiple hearth furnace. The Pittsburgh sewage treatment plant[5] now under construction has incorporated into it a flotation process for the concentration of liquid primary sludge which will be ultimately disposed of by incineration. This process is an important development as it apparently constitutes a method of sludge concentration which provides accurate control of the moisture content. Previous to this development, there has been no method available to the design engineer which guaranteed the control of the concentration of liquid sludges. This[5] fact has prevented the general use of liquid sludge incineration. As the flotation process has not been fully evaluated, as to the role it will perform in sewage treatment, and as liquid sludge incineration is not generally practiced, this paper will not consider the incineration of liquid sludges.

Sludge Disposal Methods

The major methods of sludge disposal are:

1) Sea Disposal
2) Land Fill
3) Fertilizer Production
4) Incineration.

The criterion of providing acceptable sludge disposal precludes the use of any form of raw primary sludge for land fill, or for general use as a fertilizer unless heat dried. Under certain conditions of sea disposal near recreational areas, the discharge of digested sludge may be prevented for aesthetic reasons. One of the most common methods of conditioning sludge is by digestion and sandbed drying. Due to the economics of dewatering, this system is usually limited to small communities, and therefore, the quantities of sludge produced are relatively small. Sludge which is air dried may be used for fertilizer production, incinerated, or disposed of as land fill. In such cases the installation of equipment for incineration is usually not warranted due to the high fixed cost of installation and personnel requirements for operation.

Sea Disposal

Raw or digested sludges may be pumped or barged to sea, provided that the dilution afforded is sufficient, the velocities of such a magnitude to prevent sedimentation or the area of such depth to prevent the creation of a nuisance. Should local conditions be such as to not afford the proper dilution

for the disposal of raw sludge, then the digestion process would become part of the necessary conditioning to satisfy the requirements of the disposal area. The advantages of digestion are the reduction in volume of sludge pumped or barged, and the production of gas which can be utilized for heat and power. To determine if digestion is economically warranted, for those situations where not required as a conditioning unit, these advantages should be weighed against the cost of additional operating and fixed charges occurring because of the installation of digestion. We have here, then, a disposal method which by the nature of local conditions may require digestion as a conditioning unit, barring that the installation of digestion space should result in a lower cost of sewage treatment.

Land Fill

Sludge which is to be disposed of as land fill should not have objectionable odors, and to facilitate handling should be in a compact form. Dewatered raw sludges within the range of moisture content given by air drying or vacuum filtration are not easily handled, nor odor free, unless stored for considerable lengths of time, which generally precludes their use for land fill purposes. As the design engineer has no other tool for sludge conditioning which will produce an odor free sludge, digestion is a necessary conditioning unit for this method of disposal.

Fertilizer Production

Sewage sludges to be satisfactory for fertilizer use should have sufficient fertilizing ingredients to make their sale value exceed their production cost, be free of pathogenic organisms, odors, and of such a moisture content to facilitate distribution. The advantage of fertilizer production is that the utilization of sludge for such purposes may reduce the final cost to the community of sludge disposal and incidental to that represents a conservation of our natural resources. A committee of the American Society of Civil Engineers[6] states that "Sewage solids to be used as fertilizer must be digested and dried or if digested may be kiln dried at temperatures which will destroy all inimical pathogenic organisms." This method of disposal, then provided that the proper conditioning is afforded, permits the use of digested or undigested sludges for fertilizer production. The economic value of sludge as a fertilizer depends on the nitrogen and phosphoric acid content, and the absence of objectionable quantities of grease and fibers. Sewage sludge is said to have certain plus values, but unless conditions are such to make them valuable, the fertilizer market will not recognize their presence. The nitrogen and phosphoric acid content of sewage sludge will vary according to the degree of sewage treatment and conditioning. Raw activated[7] sludges are of higher nitrogen content than raw primary sludges with the digestion process destroying approximately fifty percent of the nitrogen content found in the raw sludge. The digestion process then, by the virtue of destroying the nitrogen content, reduces the sale value of fertilizer, but has the advantage of decreasing the grease content. The variations in nitrogen content due to the method of treatment usually makes the processing of primary sludges for fertilizer production uneconomical. The activated sludges, digested or raw, having the higher fertilizer values, are, in general, the ones utilized.

The processes which will permit the production of fertilizer are:

1) Dewatering raw sludge--fertilizer production
2) Digestion--elutriation--dewatering--fertilizer production.

Fertilizer production from raw sludge results, when compared with digested sludges, in the production of larger quantities of fertilizer of higher market value, having the disadvantages of requiring larger dewatering and drying units and that all power and heat must be secured from an outside source. The advantage of the digestion process is the production of gas, smaller dewatering and drying facilities, and the permitting of a certain flexibility in operation having the disadvantages of installation costs for digestion space, the reduced value of the fertilizer produced, and the increased operating cost of digestion and elutriation.

Incineration

For a sludge to be satisfactory for incineration, the moisture content of the sludge to be processed should be sufficiently low to make incineration economical. Raw or digested sludges can be dewatered on vacuum filters to such a moisture content to permit economical incineration.

The processes which will permit incineration are:--

1) Raw-dewatering--Incineration
2) Digestion--Elutriation--Dewatering--Incineration.

The advantage of raw sludge for incineration is the higher heat value of the sludge, the disadvantages are the larger dewatering and incineration units required and the loss of digestor gas. The advantage of utilizing digestion is the smaller dewatering and incineration units required, the source of gas for fuel and power, with the disadvantage of supplying digestor capacity and operation. Digestion combined with elutriation depending on the characteristics of the raw sludge and the type of treatment involved may have the additional advantage of reducing the chemical cost for conditioning the sludge prior to vacuum filtration.

There is, of course, a question here, of the amount of auxiliary fuel which will be required for the incineration of the sewage sludge. In general[8], raw primary sludges can be incinerated without auxiliary fuel, raw activated sludges require auxiliary fuel and digested sludges may or may not require auxiliary fuel. The comparison as far as heat requirements of digested sludge against raw sludges depends on the moisture and the volatile solids content of the sludge. As both these variables are functions of the degree of treatment and the strength of the sewage, no general answer may be given which will include all cases. For any specific case, however, the possible greater additional auxiliary fuel requirements for digested sludges must be determined.

Discussion

Digestion, then, is a necessary conditioning unit to supply an acceptable sludge for land fill methods of disposal and in some cases for sea disposal. In considering the use of digestion where not required for conditioning, the question arises can it be shown generally that digestion is or is not an

economic procedure. The analysis[9] of such a problem depends on so many local factors that any conclusions that are developed on the basis of average conditions, may be worthless for any specific case. For example, consider the question of utilizing digestion as a conditioning unit for incineration. Even though the filtering and incineration units for such a process are smaller, the fixed cost of such a plant due to providing digestion capacity will usually be larger than one which incinerates raw sludge. The determination of the increase in fixed cost depends on the construction and land costs involved and the type of treatment required. One factor offsetting this additional cost, is the value of the digestor gas for fuel or power requirements. The value of utilizing the gas for power purposes depends on local utility rates, which may be so low as to make it uneconomical to install the equipment to develop power from the plant source. Another advantage of digestion, combined with elutriation, is due to the lower amount of solids to be processed, that the yearly operating costs for chemicals may be reduced. The evaluation of this factor depends on the type of treatment, characteristics of the sewage, the cost of chemicals and the degree of digestion. All of these variables then, as well as others that should be evaluated depend on local conditions, so that the answer to the question to digest or not to digest is a specific one for each case considered. The digestion process due to the storage available and the control afforded in the quantity and quality of sludge to be further processes provides some operational advantages. When a partial or general failure of processing equipment occurs due to mechanical or power failure, digestion facilities permits the holding of sludge without nuisance. In addition, the plant generally may be operated with less laboratory control, and the requirements, for the number of skilled personnel are usually not as great as in a plant which processes raw sludge. Therefore, where the incineration of raw or digested sludge including the necessary conditioning unit is of approximately equal cost, the digestion process, due to the operational advantages, should be selected. The choice of incineration as a method of disposal depends on the relative cost of incineration when compared with other available methods of disposal. All of the methods of disposal mentioned, with the exception of sea disposal contain conditioning units which will satisfactorily dewater sludge to a degree that economical incineration is possible. Whether or not it is better to utilize incineration rather than other methods of sludge disposal is a question of the evaluation of certain factors which are influenced by local conditions. In the question of fertilizer production versus incineration, the cost of fertilizer production will exceed that of incineration due to the higher fuel requirements, the additional equipment and storage space and the personnel requirements to process and market the product. These additional fixed and operating costs must be returned in the revenue derived from fertilizer sales. The market value of the sludge as fertilizer is a function of such local conditions as the degree of treatment, and conditioning, chemical constituents in the sludge, and the prices which fertilizer will command in the market. Local conditions may be such that an economic analysis will show that fertilizer production when compared with incineration will reduce the overall cost of sludge disposal. However, it would seem unwise, especially in marginal cases, with the economics of the disposal method, subject to such variables as the fertilizer market, fuel prices, the chemical composition of the sludge produced, and the interest of plant personnel in marketing the product not to provide at least space requirements and proper arrangement of machinery so that

installation of incineration facilities would be possible when desired. This objective, of course, is best fulfilled by installing initially equipment which is capable of burning or drying the sludge. Considering the case of land fill versus incineration, the incineration process is higher in first cost due to the fact that incineration facilities must be installed and in operating costs due to the necessary power and labor, as well as auxiliary fuel requirements. Under such conditions, incineration can only be economically justifiable when the cost of the land fill method due to some local factor as the length of haul required is such to exceed the cost of incineration. Sea disposal does not require the conditioning units of dewatering that are required by incineration. There is, however, for this method the fixed cost of the necessary docking and shipping or outfall facilities, and the operating cost of the labor and power required to transport or pump the sludge. If such costs will exceed that of vacuum filtration and incineration, depends on such local factors; to mention only a few, as the length of haul, volume of sludge to be handled, labor costs and power rates. As the question of utilizing incineration versus any other method of disposal is essentially an economic problem which is resolved on the basis of local conditions, the answer for each case considered is specific to the locality.

CONCLUSIONS

The only conclusions, therefore, which are generally warranted are the following:

1) Digestion is a necessary unit of conditioning where sludge is to be utilized for land fill or in some cases of sea disposal.

2) Where not required as a conditioning unit the ultimate costs of sludge disposal must be reduced to justify the use of the digestion process.

3) The factors which determine the economic advantage or disadvantage of utilizing digestion as a conditioning unit and incineration as a method of disposal are so dependent on the locality considered that no general conclusion may be reached which will be satisfactory for all cases. Each problem, therefore, is specific in itself.

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CALCULATION OF MAC OF RADIOACTIVITY IN AIR AND WATER

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(Proc. Paper 1174)

ABSTRACT

The fact that radiation damage is proportional to absorbed energy provides a means for calculating MAC values for many radioactive environmental contaminants. These calculated MAC values are based on a maximum exposure rate of 300 millirem per week, corresponding to the absorption of 30 ergs per gram of tissue for beta or gamma radiation. If the biological behavior of any particular radioisotope is known, then the maximum permissible contamination may be calculated that would result in exposure at this rate.

Progressively greater quantities of various noxious agents and nuisance substances are being introduced into our environment by our continually expanding technology. Although great efforts are made to deal with the problem, it is recognized by all that certain environmental contamination is a price that we must pay for the benefits of our modern society. Organized counter measures against environmental contamination are based on the fact that for any undesirable substance there exists some threshold for the concentration of that substance below which it is not a health hazard. Engineers, recognizing this, strive to design processes which will maintain environmental contaminants as far below the threshold value as possible.

In recent years the problem of environmental contamination has been brought into sharp focus as a result of the successful harnessing of nuclear energy. For the first time in our history, we are faced with the task of "disposing" of wastes that cannot be disposed of.(1) The radioactive fission products, the so-called "ashes" from the nuclear reactor, cannot be operated

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on, either physically or chemically, to make them lose their radio-toxicity. They can only be stored and permitted to decay away over a period of time measured in centuries. Since we cannot change the toxicity of the waste materials, our only alternative is to limit the environmental concentration of radioactive substances to some safe level.

Although radioactive contamination bears many similarities to its non-radioactive counterparts, there are some essential differences. The main difference is between the mechanisms of toxic action of these two broad classes of substances. Non-radioactive poisonous materials act on an organism in a great number of different ways. They may be physical poisons, they may be corrosive, or they may act to disrupt enzyme systems, to name just a few. In the case of radioactive agents, the biological damage is thought to be caused by the absorption of energy from the radiations and is, in fact, proportional to the absorbed energy. This fact greatly simplifies the task of setting maximum permissible concentrations of radioisotopes in air and in water. It is no longer necessary to investigate the toxicology of every radioactive compound before setting MAC values. Until the acquisition of specific data from the toxicology laboratory, the common denominator, energy absorption, can be computed, and, if certain biological information is known, maximum allowable concentrations can be calculated. The second major difference between radioactive and non-radioactive substances is the quantity of material that is toxic. In the case of radioactive materials, the poisonous concentrations are smaller by orders of magnitude than in the case of the non-radioactive materials. In the case of lead, for example, the commonly accepted maximum permissible atmosphere concentration is 150 micrograms per cubic meter. In its radioactive form, the maximum permissible concentration is about one-millionth of a microgram per cubic meter. In most cases, therefore, when dealing with radioisotopes, chemical toxicity can be neglected. It should be pointed out that the minute quantities, when specified in ordinary units of weight, of radioactive poisons are of no consequence as a measurement problem. Since we are interested in radioactivity, or decaying atoms, units of mass are not significant. The important property is the number of decaying atoms per unit time, or the activity of the substance in question. This is conveniently measured by a unit called the "curie" and defined as the quantity of radioactive material in which there are 3.7×10^{10} nuclear disintegrations per second.(2) Pulse counting instruments, such as Geiger Mueller and scintillation counters permit the detection of a single nuclear decay.

Since radiation damage is in all cases a function of absorbed energy, the unit of radiation dose is defined in terms of absorbed energy. The first such radiation unit, called the roentgen or the r, is "that quantity of x or gamma radiation such that the associated corpuscular emission per .001293 grams of air produces, in air, ions carrying 1 esu of quantity of electricity of either sign."(2) It can be shown that one roentgen corresponds to the absorption of 83.8 ergs per gram of air. Because energy absorption depends on the atomic number of the absorber, 1 r corresponds to about 95 ergs per gram of tissue. Since the roentgen technically refers to energy absorption from x or gamma rays, another unit called the roentgen equivalent physical or the rep is used when referring to other radiation. The rep is defined as the absorption of 95 ergs per gram of tissue. Because of technical difficulties in measuring the roentgen for high quantum energies, a new unit called the rad is used. The rad is defined simply as the absorption of 100 ergs per gram of tissue.

The basic measurement of the rad is made with a calorimeter, in contrast to ionization methods for the other units. Although there is a small numerical difference between a rep and a rad, the two are considered to be biologically equivalent. Still another unit, called the rem, is introduced as a normalizing factor to account for the different damage producing properties of different radiations.(3) For purposes of orientation, it might be pointed out that 25 r is about the minimum dose that is biologically detectable in man, and that 400 r is the LD 50 dose. As a result of animal experimentation and a backlog of experience dating back to the beginning of the century, the maximum permissible exposure rate has been set at 0.3 r, or 300 milli rem per week. The problem, then, is reduced to limiting the concentration of radioisotopes in water and in air such that continuous exposure will result in a weekly dose not greater than 300 mr.(4)

To calculate the maximum permissible concentration of a radioisotope in drinking water, certain biological as well as physical data must be available. These include:

A. Physical
   1. Type of radiation (α,β,γ)
   2. Energy of radiation
   3. Physical half life, or the rate of radioactive decay

B. Biological
   1. Identification of storage compartments within the organism
   2. Turnover rate in each compartment
   3. Critical organ
   4. Fraction of ingested radioisotope that is systemically deposited
   5. Ratio of weight of element in the critical organ to weight in total body

The radioisotope may be stored in one or more "compartments" or tissues, in the body. In many cases, the uptake by the organ in which it is stored can be considered instantaneous with respect to the time that it will be retained by the organ. After uptake, it will be slowly excreted. If its passage through subsequent organs or tissues (blood, kidney, etc.) on the way out of the body is rapid compared with the rate of release from the storage organ, then this latter rate is the dominant one, and the elimination from the body will appear to follow first order reaction kinetics. In this simplest case, the elimination of the isotope is described by

$$A = A_0 e^{-\lambda t},$$

where A is the activity at time t after deposition of A_0 units of activity, and λ is the effective elimination constant. The effective elimination constant is the sum of the physical decay constant and the biological elimination constant; it is related to the effective half life, T_{eff}, by

$$\lambda_{eff} = \frac{\ln 2}{T_{eff}}$$

and

$$\frac{1}{T_{eff}} = \frac{1}{T_{Bio}} + \frac{1}{T_{phy}}$$

Maximum allowable concentrations are computed on the basis of a "critical organ". Although the critical organ is very frequently the one in which the isotope is retained by the organism, this is not necessarily true in every case. Relative radiosensitivity and mass of the organ, for example, are two other considerations that go into the choice of the critical organ.

This simple monomolecular model may be illustrated with the calculation of the maximum permissible concentration of carbon 14 in drinking water.

Effective energy = .053 Mev per disintegration

Physical half life = 5700 years

Biological half life = 30 days

Effective half life = 30 days

Effective elimination constant = $\frac{.693}{30}$ = .023 day^{-1}

Critical organ = fatty tissue, mass = 10,000 gms

Fraction absorbed into critical organ from GI tract = 0.475

Daily water intake = 2500 milliliters per day

Fraction of total body carbon in the critical organ = 0.6

Tolerance dose = 300 mr/week = 43 mr/day.

We now want to calculate the body load of C^{14} that will irradiate the fatty tissue at a rate of 43 mr per day.

$$.043 \frac{\text{rad}}{\text{day}} = \frac{\frac{Q}{W} \frac{\mu c}{\text{grams}} \times 3.7 \times 10^4 \frac{d}{\text{sec}\,\mu c} \times 8.6 \times 10^4 \frac{\text{sec}}{\text{day}} \times 5.3 \times 10^{-2} \frac{\text{Mev}}{d} \times 1.6 \times 10^{-5} \frac{\text{ergs}}{\text{Mev}}}{100 \frac{\text{ergs}}{\text{gram}} / \text{rad}}$$

Solving for the activity in the fatty tissues, we get

$$Q = 150\ \mu c$$

Since 60% of the total body carbon is in the fat, the total body burden may be determined:

$$\frac{150}{0.6} = 250 \text{ microcuries}$$

To calculate the maximum concentration in drinking water that would load the body with a maximum activity of 250 uc, we merely equate the activity ingested to the activity eliminated.

Using the values given above for the daily water intake and for the fraction absorbed into the critical organ from the GI tract, we have

Rate of intake = Rate of elimination

$$C \frac{uc}{ml} \times 2.5 \times 10^3 \frac{ml}{day} \times .475 = \lambda\ day^{-1} \times Q\ uc$$

Solving for C, we get

$$C = 4.4 \times 10^{-3} \text{ microcuries per milliliter}$$

It is obvious that if radiocarbon is continually ingested at the calculated rate, then an infinitely long time will be required to reach the maximum permissible body burden. The length of time to reach any body burden may be

easily calculated. To reach 99% of the maximum

$$0.99 = 1-e^{-\lambda t}$$
$$t = 198 \text{ days, or}$$
$$6.6 \text{ half lives}$$

The case of carbon is particularly simple, since the radioisotope is a pure beta emitter. In the case of a beta-gamma emitting radioisotope, the dose due to the gamma rays must be added to that due to the betas. In general, however, the dose due to the gamma rays will be much smaller than that due to the beta radiation.

In arriving at the beta-ray dose, it was assumed that all the energy from the beta rays was completely absorbed in the critical organ. Because of the high penetrating power of gamma rays, most of them pass out of the critical organ, giving up only a small fraction of their energy. Important factors in the determination of the absorbed energy from a uniformly distributed gamma emitting isotope are the size and shape of the critical organ. Furthermore, it follows that the dose rate within the organ is not uniform throughout the organ, despite the fact of uniform distribution of the radioisotope.

By approximating the shape of organs as spheres or cylinders, it is possible to calculate geometrical factors that permit the calculation of the average gamma ray dose rate to any organ containing a uniformly distributed radioisotope.(5)

$$D = \frac{Q}{W}\ \rho\, kg, \text{ where}$$

D = r/day
Q = microcuries
W = weight of critical organ in grams
ρ = tissue density
k = source strength, r/day/μc at 1 cm
g = geometrical factor

For the case of a beta-gamma emitting isotope, the maximum activity in the critical organ is calculated by combining the beta ray and gamma ray contributions:

$$.043 = \frac{Q}{W}\frac{\mu c}{gms}\left[\left(\frac{3.7 \times 10^4 \frac{d}{sec}\ \mu c \times E\ \frac{Mev}{d} \times 1.6 \times 10^{-6}\ \frac{ergs}{Mev}}{100 \text{ ergs/gram/rad}}\right) + \left(\frac{gms}{Cm^3} \times k\ \frac{r}{day}\ \mu c \times g\ cm\right)\right]$$

The equations developed above are based on absorption and storage of the radioisotope into a critical organ. Implicit in the equations is the fact that the isotope is in some form that will permit its passage from the GI tract into the critical organ. If this is not true, or if the uptake of the radioisotope by the body is very small, such as the case of the trace elements, then the non-systemically deposited activity will irradiate the GI tract or the urinary tract as it passes through the body. This presents very little difficulty, however, since the same equations can be used in this case.

The establishment of maximum permissible values for atmospheric concentrations may be relatively simple in the case of certain gases, and is extremely difficult in the case of radioactive dusts. Generally, MPC values consider external exposure, in which the man is thought of as being completely submersed in an ocean of radioactive air, and internal exposure due to the inhalation and absorption into the body of the radioactive materials.

In an infinite absorbing medium, the energy absorbed per unit mass of air is equal to the energy emitted per unit mass of air. Since the maximum permissible dose rate for continuous exposure is 43 mr per day, the maximum permissible atmospheric concentration may be calculated as follows:

$$.043 \frac{r}{day} = \frac{\frac{Q\mu c}{Cm^3} \times 3.7 \times 10^4 \frac{d}{sec\ \mu c} \times 8.64 \times 10^4 \frac{sec}{day} \times E_{eff} \frac{Mev}{d} \times 1.6 \times 10^{-6} \frac{ergs}{Mev}}{1.293 \times 10^{-3} \frac{grams}{Cm^3} \times 83.8\ ergs/gram/r}$$

If the radioactive gas is biologically inert, then submersion is the only factor that is considered. If, on the other hand, the gas, after inhalation, diffuses across the alveolar membranes into the blood and is subsequently stored in some body tissue, then the maximum permissible body burden must be calculated which, together with the external irradiation, will result in a maximum exposure of 43 mr per day. Knowing this, the MPC in the air can be calculated. Some of the biological data that must be known in order to make such calculations are the diffusion constant for the gas across the alveolar membranes, the solubility of the gas in the blood, the diffusion constant for the gas across the capillary and cell walls, the solubility of the gas in the tissue, and its turnover rate.

Because the biological effects of focal radiation sources embedded in tissue are not completely known, we cannot, at the present time, calculate MPC values for dust particles that are based on sound biophysical considerations. Some of the more obvious parameters that must be considered are:

1. Particle size distribution
2. Type and energy of radiation
3. Specific activity of the particle
4. Particle solubility
5. Pulmonary retention

Until such time that our knowledge of the relationship among these parameters and their relationship to pulmonary radiation damage is increased, MAC calculations for particulate matter whose biophysical properties are not known are based on the lung model of the standard man.(6) According to this model, particulate contaminants are divided into two general categories, viz: soluble and insoluble. Soluble particles are dismissed as a pulmonary hazard on the basis of their rapid removal from the lungs after solution. That this generalization can lead to undesirable consequence is evident from the fact that many soluble salts, especially those of the lanthanide and actinide elements, form very tightly bound organo-metallic complexes with the protein in the lung. Should this happen, then a situation is created that is most conducive to the genesis of pulmonary damage.

In the case of the insoluble particle, when specific data are not available, it is assumed that 25% of the particles are exhaled and 50% are deposited in the upper respiratory tract and subsequently swallowed. (These assumptions are also applicable to the soluble particles.) Of the 25% that are deposited in the deep respiratory tract, one half is eliminated from the lungs and swallowed during the first 24 hours after exposure. The remaining 12 1/2% is retained in the deep respiratory tract, and is eliminated with a half life of 120 days.

When this model is used, the dose is calculated on the basis of uniform distribution of absorbed energy. That this condition is not true is obvious when one considers that each dust particle is a focal point of radiation, and that the absorbed energy gradient around a radioactive dust particle may be very great. Using a point source dose function,(7) the calculated dose from a one milli-microcurie S^{35} particle is 94,000 rep per day at a distance of 5 microns from the particle. At 50 microns, the dose rate drops off to 1,400 rep per day, and at 300 microns the dose is down to zero rep per day.(8) Several experiments suggest that this non-uniform dose rate is of no serious consequence. These experiments suggested, on the contrary, that for a given total amount of absorbed energy, the biological damage was less for the spatially concentrated case than for the uniformly distributed case.(9),(10) On the basis of these results, therefore, the assumption of uniform energy absorption in the calculation of MPC values seems to be justified.

Using the basic ideas discussed above, maximum permissible environmental contamination levels for continuous exposure have been calculated for a number of radioisotopes. Although calculations based on energy absorption are valid, it must be emphasized that such calculations depend on accurate biologic data. Because of this strong dependence on biologic data, and because of the difficulty of obtaining these data, direct toxicological information is used whenever it is available. Direct evidence of this type is used, for example, to set maximum permissible limits on radium, plutonium and strontium exposure.

In summary, MAC values for radio-contaminants in the air and water, may, in the absence of specific toxicological data, be calculated on the basis of energy absorption by the body tissues from the radiations emitted by the radioisotopes. At the present time, an upper limit of 300 millirem per week, corresponding to 30 ergs per gram of tissue from beta or gamma radiation, has been set for continuous exposure to these radiations.

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SELECTION OF SITES FOR ATOMIC ENERGY PLANTS[a]

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ABSTRACT

Careful site selection for atomic energy plants is a most important advance planning function. The most important environmental elements affecting site selection are the geology, hydrology and meteorology of the area.

The purpose of this paper is to discuss some of the more significant problems in site selection for atomic energy plants based on experience with projects constructed and operated for the U. S. Atomic Energy Commission. Special emphasis is given to environmental considerations because it is in this area that sanitary engineers whether employed within the industry or with public agencies are most likely to be called upon for judgment and service.

Few, if any, industries call for the extensive and careful advance appraisal of sites for proposed plants and for on-site location of plant structures and facilities that is required in the atomic energy industry. There are many reasons why this is so; important among them are the following:

1. The products and wastes of the industry are both toxic and radioactive, therefore, they present potential hazards to man and his environment.
2. The kinds of radioactive materials used are many and their levels of activity vary widely.
3. The period of radioactivity of certain nuclides is long—hundreds of years—therefore special consideration is required in their storage and disposal.

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4. The technology of the industry is advancing rapidly, thus presenting problems of expansion and obsolescence.

5. The effects of exposure to radiation, especially on a cumulative basis, are not too well established.

6. The staff of regulatory agencies charge with responsibility for public health and safety are not yet as well trained in the technology and experienced with problems of this industry as with others.

In selecting a site for a new plant in most industries, the following considerations are of real importance and must be evaluated:

1. Availability of and distance to sources of raw materials.

2. Proximity to customers to be served.

3. Availability of labor.

4. Suitability of housing and community services for employees.

5. Adequacy of transportation.

6. Reliability of supporting utility services.

7. Potentiality for expansion.

In the atomic energy plants, radiation and its unique effects on man and his environment introduce additional considerations which must be appraised. Radiation is a new industrial contaminant. It is a force which existing and future generations of sanitary engineers must cope with in many ways. It is also a new tool of much promise to many professions.

Plants using atomic energy may be grouped in five general classes:

1. Plants for producing nuclear fuels from raw ores and reclaimed fissionable materials and for fabricating fuel elements. Typical is the Feed Materials Plant at Fernald, Ohio. For the most part such plants deal with radioactive materials of low specific activity, long half life and high specific gravity. They are similar to specialized chemical metallurgical plants. Because of the factor of radiation more than average attention must be given to protection of employees and to disposal of waste in many forms.

2. Plants for enriching fissionable materials for use in nuclear fuels. The great gaseous diffusion plants at Oak Ridge, Tennessee; Portsmouth, Ohio and Paducah, Kentucky are typical ones. They also deal with products of long half life and low specific activity. Processing is in the form of gaseous fluorides of uranium. Under proper operations, releases of fluorine gas and wastes as insoluble fluorides present no serious environmental hazards.

3. Institutions using nuclear materials primarily for research and development. These include laboratories, hospitals and manufacturing plants of various kinds at which relatively small quantities of radioactive materials are used. For the most part, but not always, the levels of radioactivity are low. Such institutions are numerous, widely spread geographically and expanding in uses of nuclear energy.

4. Nuclear reactors for: (a) test and research purposes and operated at low levels of energy and under most conservative conditions. The so-called swimming pool reactors are representative of this group, (b) testing new design concepts, and new fuels and fuel assemblies. Representative of these types are the test reactors at the National Reactor Testing Station, the Oak Ridge and Argonne National Laboratories and special reactors at other AEC installations for carrying out controlled criticality tests. At the test reactors in the so-called SPERT series at NRTS planned excursions in power levels beyond conservative limits may be carried out, (c) testing materials and facilities for production of fissionable materials, or for developing heat to be used for power or other services. Such reactors are charged with substantial amounts of nuclear fuel and usually are operated at high power levels. They would include the Materials Test Reactor (MTR) at NRTS, the production reactors at the Hanford and Savannah River projects, and the pressurized water reactor under construction near Shippingport, Pennsylvania.

5. Plants for processing irradiated fuel elements to separate unspent fuel from fission products and fissionable material bred in the reactor. Plants of this kind are at the Savannah River and Hanford Works and at the NRTS.

There are factors in evaluation of sites which are common for all of these classes of atomic energy plants. The problems have much more depth, however, at those plants where large volumes of high level long lived radioactive materials are to be used or processed and from which radioactive waste products are to be released. Such plants are the nuclear reactors operated at high power levels and containing substantial amounts of fuel which has been irradiated over a considerable period of time producing fission products and fissionable material. Others are the plants at which spent fuels are processed by aqueous chemical methods. The value of the fuel and fissionable material is great and, therefore, every effort is made to prevent their loss. The fission products are by-products to be disposed of as wastes or reclaimed for use as radioactive sources, if it is profitable to do so.

The necessity of storing, treating and disposing of wastes from day-to-day operations is one of the most important considerations in selecting a site for an atomic energy plant. The possibility that large amounts of radioactive material on hand in such plants, but under strict control, might be released in case of an extraordinary incident is another consideration which calls for realistic evaluation. Examples of situations contributing to hazards under normal day-to-day operations are human errors or undetected defects which may develop in critical equipment. Hazards under extraordinary circumstances might be deliberate sabotage or gross damage resulting from a first-time catastrophe in the specific area.

A reasonable assessment of the probability that a situation could develop to present hazards to a plant, its operators or people and property in the surrounding area is a prime obligation of the industry. It is also an indirect and growing responsibility of public officials. Arrival at such an assessment calls for a wide sweep of technical competency involving many professions and the skill and experience of numerous crafts. Developing a team to give balance and perspective in resolving problems of site selection for atomic energy plants is no small order.

A must item in considering a new site is a study of population densities in the immediate area and in the general region of the site—say out to a distance of 30 miles and in the case of large cities even further. Data of this kind are basic to an evaluation of the possible effects of hazards of environmental significance. In addition, consideration should be given to the possibility that new satellite communities might develop to house plant employees and their families. It would be desirable also to ascertain the availability of vacant land which could be acquired as a peripheral buffer zone around the plant. Land so acquired might later prove to be a good investment for management.

A second important item is the general topography of the site and the region in which it is located. A flat open plain on high ground may have the advantage of more consistent atmospheric conditions for dilution of gaseous wastes which may be released. Ordinary drainage of such a site would present no serious problems. On the other hand, plant sites in deep valleys generally are less favorable for dilution and dispersal of gaseous effluents and they may be subject to flooding and other site preparation problems. They may be nearer, however, to existing rail or water transportation and, if necessary, could be easily camouflaged, if this were a desirable factor in plant location.

The need of a firm source of water supply of suitable quality is a requirement which hardly needs recording to sanitary engineers. Yet it is a factor one all too frequently inadequately appraised. Atomic energy plants have very strict requirements as to quality of water and continuity of water service. The volumes of water used for cooling purposes in operating nuclear reactors, chemical processing and gaseous diffusion plants are very large. The cost of facilities for pumping, treating and storing water at such plants is a substantial percentage of the total capital investment. There is a good probability that new atomic energy plants will be enlarged as the industry expands. It would not be prudent, therefore, to consider a site which had a limited water supply potential even though the source appeared to be adequate for the initial facilities.

Since radioactive wastes from normal operations within the atomic energy industry or from accidental releases not planned are likely to increase substantially the background of radiation of the ground, nearby waterways—surface or underground—and the atmosphere appraisal of environmental conditions at a proposed site are of prime importance. This is a team job for specialists both within and outside the industry.

Collection of the necessary environmental information required on which to base sound judgments requires time especially in dealing with geologic, hydrologic and meteorologic considerations. Information over limited periods could be misleading but, of course, is better than none. Specific on-site data are needed as well as those for the general region of the proposed plant. Integration of such information to develop a judgment requires the service of specialists. Management interested in obtaining land for future plant sites would do well to prepare for the collection of such information as far in advance of making decisions as to sites, if this is possible.

In a fast growing industry the newer trends in technology must always be taken into consideration in site selection. This is especially true in disposal of radioactive wastes and the environmental problems related to geology, hydrology and meteorology.

Geologic Factors

For purposes of construction any thorough study of a proposed plant site calls for geologic exploration. In the case of such facilities as hot cells, nuclear reactors and chemical processing plants, massive concrete structures must be built to shield against radiation. It is essential, therefore, that geologic data as to the bearing capacity at the site for these heavy loadings be well established.

Since underground tanks for storage of radioactive materials and especially wastes will be needed at most atomic energy plants, it is important that any corrosive condition of the soil in the area of these tanks and the pipes to them be ascertained in order that corrective measures may be made as needed. Any instability of the soils resulting from settlement or the effect of more insidious forces such as slides or earthquakes could be dangerous to many vital structures and facilities. This is particularly true in the case of large reactors and chemical processing plants. Contingencies of this kind should be considered as unfavorable factors in considering a site.

At or near the sites of atomic energy plants, it is reasonable to assume that there will be release of radioactive liquid wastes and perhaps a need for burial or certain solid radioactive wastes. It is important that the capacity of the soils to receive, retain, absorb and to drain away liquid wastes be ascertained. If a plant is to produce large volumes of low and intermediate level radioactive wastes a site whose subsoils are capable of draining wastes pumped to surface pits or subsurface cribs will be advantageous. This is particularly true if the soils have adsorbtive or absorbtive properties for the isotopes which characterize the waste streams. Where the depth to the water table is such that subsoils have capacity to receive large volumes of the wastes above the water table this would be a favorable condition. Situations of this kind are likely to be found at sites where the annual rainfall is low as at the Hanford Works in the State of Washington. The permeability and exchange capacity of subsoils, the rate and direction of flow of the ground waters and any point of reappearance of them at the surface in the vicinity of a site be known.(1)

With such information, reasonable judgment can be made of the relative value of sites for installation of facilities for ground disposal of low level wastes. Some radioisotopes in wastes are likely to migrate through soils more rapidly and with less absorption than others. Ruthenium^{106} is one of these.(2) Aqueous nitrate wastes(2) move more rapidly than those in other solutions.

Research sponsored by the U. S. Atomic Energy Commission is in progress to ascertain the properties of various soils and soil constituents to remove radioisotopes from waste streams and to determine the movement of them through soils. Experiments are being carried out by applying wastes to soils in place and also in columns under laboratory conditions. Such research is to determine the theoretical aspects of absorbtion phenomena observed and to classify soils having favorable and unfavorable characteristics. It is hoped that as a result of this research using various tracers, it may be possible through a combination of laboratory tests on core samples and field tests on-site to determine the dynamics of flow of liquids through the soil in order to be able to appraise the fate of liquid wastes when released to the ground. The development of procedures and techniques for such a testing program would give a basis for allowing the industry to use within limits available dilution factors in nature.

Research[3] in these fields has been carried out at ORNL, the Hanford Works, the NRTS, Los Alamos, The Brookhaven and Oak Ridge National Laboratories and at Yale and California Universities. Because of the number of radionuclides in various waste streams and the great variety of soils in different sections of the United States this is a long term research program.

The possibility of being able to dispose of high level wastes to the ground presents a new kind of problem in site evaluation for chemical processing plants. Storage of such wastes in underground tanks is currently practiced in most areas as an expedient—not as an ultimate method of disposal. It permits concentration of the wastes and decay of the shorter half life constituents. But in the case of Sr^{90} and Cs^{137} with half lives of 28 and 33 years respectively, it is possible that leaks in the tanks might develop before the level of activity in these radioisotopes decay to safe limits for release to the ground. Transfer from the original tanks to new ones would permit deferment of the ultimate disposal problem. It is fraught, however, with hazards and would be costly. Furthermore, it may necessitate dedication of valuable land as a radioactive graveyard.

Geologists consulted[4] have indicated that two methods of ground disposal might be feasible for highly radioactive liquid wastes from chemical processing of spent fuel elements. One is by pumping them into cavities dissolved in deep salt deposits or in salt domes. The other is by pumping pretreated wastes to the connate brines in closed basins at great depth and in areas where natural resources would not be unfavorably affected. The potentialities of such a method of disposal are attractive. Much research and development work must be carried out, however, before it can be established that these methods of disposal are economically feasible and safe or acceptable to responsible regulatory agencies.

Should either or both of these methods develop to be feasible, knowledge of the existence of suitable deep strata under a proposed site for a chemical processing plant would be important in evaluating that site. It is conceivable that with an ever increasing use of nuclear energy for power purposes the production of fission products would far outrun the demand for selected isotopes in radioactive waste for use as radiation source. In this case direct disposal of much of the high level wastes from chemical processing plants to deep strata might prove to be less costly and safer than storage of these wastes in tanks with or without extraction of some of the long half life radioisotopes. Such methods have the disadvantage of possible loss of the wastes and the energy they contain should technological development establish that they have value. Removal of long half-life wastes from the environment of man has compensating advantages.

Within the atomic energy industry there is much interest in immobilizing radioactive waste by fixation in a solid media. In one method the wastes are concentrated by evaporation. Residues in the form of nitrates or fluorides are further heated and converted to oxides[5] in powder or pellet form. These can be elutriated by water or acids and any soluble nuclides removed subsequently to be absorbed on clays[6] or other media which when heated to high temperatures would form a ceramic mass. The wastes in solid form could then be inventoried and stored in dry ventilated vaults or in underground caves where they could be stored indefinitely and be subject to periodic inspection. Handling of these solid radioactive units behind shielding and with modern transport equipment present no unsurmountable problem. Proximity of easily mineable dry areas to a chemical processing plant would be a site asset.

Hydrologic Factors

Within limits ability of surface waterways to receive, dilute and alter wastes from municipalities and industries without jeopardizing the usefulness of these waterways as sources of domestic or industrial water supplies, for transportation or for various recreational uses is well understood. Knowledge of the effect of radioactive wastes on waterways and on the biologic life therein is still fragmentary. The right to dispose of low level radioactive wastes to surface waterways has economic potential to the atomic energy industry. In site selection for plants evaluation of safe dilution factors in waterways is an important item. It is not, however, a task which can be concluded after the analysis of a few samples. Rather, it is one which requires much planning and a continuing investigation in which the characteristics of the waterway and the wastes are studied and their effects each on the other determined. It will take time to establish these dilution possibilities and their limits on a technical basis comparable to current knowledge as to the capacity of waterways to receive domestic and industrial wastes without creating hazards to the public health or objectionable conditions in the waterways themselves.

Studies of the Columbia River[7] downstream from the Hanford Works, the Mohawk River[8] below the Knolls Atomic Laboratory near Schenectady, New York and the work carried out by sanitary engineers at Harvard University on waterways[9] in New England have revealed that the pattern of dilution of radioactive liquid wastes in streams and lakes follow that of diluting wastes from other industries. The known uptake of radioactivity by the suspended material in the water, by silts and biological growths on the stream bed and by fish life in various stages of development introduces new areas of significance. An important consideration is the fact that a radioisotope may become absorbed in or on particles in suspension in a river. Particles which have absorbed radioactivity and billions of others will settle out in a stream at a point where the velocity is lowered. Later when there is heavy rainfall on the watershed the flow and velocity of the stream will increase. Some settled radioactive particles will be picked up and perhaps be re-deposited many times further on downstream. If the half life of the radioisotope is long such as that of Cesium^{137} or Strontium^{90} it would retain its radioactivity during these various environmental experiences.

It is for these reasons that in considering a site for atomic energy plants careful study should be made of waterways to which runoff from the area and especially waste streams from plants would drain. Such a study should include the time of flow—direct or through soils—to the waterways and to downstream users. Special attention should be given to downstream intakes to sources of public water supplies and industries whose products might be sensitive to radiation. An example would be a source of water for a paper mill whose products ultimately may serve the photographic industry.

The Atomic Energy Commission is sponsoring[10] studies of the fate of radioisotopes in streams and other surface waterways in order to accumulate sufficient information and to aid in developing instruments for field investigations which will make it possible to appraise the dilution factors in waterways. It plans to expand these studies as a co-operative effort with federal and state officials along lines which have been followed at KAPL, Hanford and Harvard. Similar studies need to be made on coastal and estuarian waters and on the larger lakes of the nation.

Meteorological Factors(11)

Practically all places where radioactive materials are processed will have some releases of radioactivity to the atmosphere. The degree to which gaseous effluents from fuel fabrication plants, research laboratories, air cooled reactors and chemical processing plants may need to be decontaminated in order to eliminate hazard on and off-site is dependent on the extent to which releases to the atmosphere will become diluted. The cost of clean-up facilities for gaseous effluents—either as true gases or as particulates—is high. Facilities for a plant located so that atmospheric dilution is characteristic and can be depended on during periods when the plant is operating could be built at a lower cost than those for a plant so located that conditions for atmospheric dilution are not favorable. A plant site near the shore on coastal waters or on one of the Great Lakes might be so designed and operated that advantage could be taken of offshore winds. There is, however, no reason that coastal location would have sufficient offshore winds to make such a location feasible. A meteorological survey of the location could determine this.

The height and location of stacks for nuclear reactors and chemical processing plants should be selected with great care and always with advice from a meteorologist. In areas where temperature inversions are frequent and prolonged as in a river valley, high stacks may be necessary to bring the released effluents above the inversion layer. Otherwise diffusion would be limited and serious concentration of contaminants under the inversion ceiling could occur. A decision whether or not to install heating facilities in a stack in order that the effluent stream may rise well above the top of the inversion layer can best be made after consultation with a meteorologist.

All too frequently judgment as to plant location with reference to nearby communities, other industrial plants and even other units of the same industrial complex are made based almost wholly on records of wind direction frequency. Such records while valuable should be further examined as to the hours of the day and seasons of the year when winds are from the various directions. Furthermore, these frequency relationships should be studied on the basis of wind velocities. Rain and snow will bring atmospheric contaminants to the ground. Precipitation following periods of inversion and when wind velocities are low will present special site problems and an increase in surface contamination and runoff to local streams.

In matching plant operating practices with atmospheric probabilities the design or operator will be in a much better position to make judgments than if they deal only with gross meteorological data. For example, should records show that consistently there would be ground concentration of radioactivity caused by looping of stack releases in the morning hours when employees were arriving—it would be prudent to adjust operations so that the degree of contamination of the released effluents would be lessened or the hours of arrival of employees altered.

Often judgment as to meteorological conditions at a site must be made by integration of data from several weather stations many miles distant. Taking into account the topography of the region, the skilled meteorologist can arrive at reasonably satisfactory judgment of probable atmospheric condition in the site. For a specific site in an area where meteorological data are scant, often it is advisable to ascertain local atmospheric conditions by using smudge pots, balloons or some aerosol tracer such as cadmium sulphite or

radioactive tracers. This is specially true where the topography of the site has special features such as a river bluff, a narrow pass or a hill draining toward an open valley. Under these situations atmospheric drainage may be subject to peculiarities which would require marked correction of general regional meteorological data.

The micro-meteorology of a specific site is of much greater importance than is generally realized. It is especially significant in making decisions as to the location of major buildings each in relation to the other, in planning for future expansion, in locating of air intakes with respect to points of release of effluent discharges and even in the height, shape, and surface contours of buildings and structures.

The design engineer and the contractor for plant structures and facilities will need certain meteorological data in sizing facilities and in planning work schedules. Evaporative coolers and equipment for air conditioning, space heating and ventilating which can be designed for actual conditions at a specific site will be much more satisfactory than those based on general area data. The construction contractor who is informed in advance of the range of weather conditions likely to be encountered during the period of erection of buildings or installation of facilities can eliminate many contingency extras in his bidding. On a large construction job daily meteorological forecast are of inestimable value. These examples will serve to show the importance of obtaining accurate meteorological data for proposed new atomic energy sites.

In conclusion, site selection for atomic energy plants is a most important advance planning function. Errors in plant layout are much more difficult to correct in the atomic energy industry because areas which once became contaminated by radioactive wastes containing long lived nuclides could present serious future problems.

The understandable concern of the public and officials of public regulatory agencies over the potential hazards to man and his environment associated with radiation as a new industrial contaminant presents important problems in public relations which management must face. A most effective method of meeting this situation is to evaluate the environmental elements in the vicinity of a proposed site well in advance of its selection.

Among the most important factors are the geology, hydrology and meteorology of the area. The advice of experts in these fields is a must item in site evaluation especially if radioactive wastes are to be released from plant unit.

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SED RESEARCH REPORT NO. 11

ON STATUS OF REFUSE COLLECTION AND DISPOSAL

BY The Sanitary Engineering Research Committee, Refuse Section

Synopsis: A preliminary survey was completed during 1955-56 both by direct discussion and postal inquiry concerning the present status of refuse collection and disposal as well as future needs for additional research and development in this field. The results of this investigation are summarized and evaluated.

Purpose

A preliminary survey was undertaken to determine the present status of engineering research and development in the refuse collection and disposal field. In addition to personal discussions, letters were written to some 25 authorities directly interested in the various phases of refuse disposal; these authorities included representatives of municipal collection and disposal agencies, State and federal sanitation programs, university and research staffs, as wells as consulting engineers and professional society committees.

In particular, an attempt has been made to enumerate specific projects that may be worthy of further research and development. The letter correspondence and personal discussions were initiated by Refuse Section personnel, starting about January 1955 and have continued through August 30, 1956.

Current Research Investigations

A preliminary estimate of the current research in the refuse disposal field is herewith summarized. This information is not presented as a detailed and comprehensive listing of all research development work, but rather it is a summary of the data on research investigations that the Refuse Section of the Research Committee(1) has been able to collect and it is contemplated that further detailed survey studies will amplify this preliminary research information.

Greeley(2) prepared a special listing of current related refuse research activities summarized in part as follows:

The American Public Works Association Research Foundation has undertaken to stimulate research on the discharge quality obtained from various refuse incineration stacks. The American Public Works Association also has a refuse collection committee and a refuse disposal committee, each charged

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with the responsibility of carrying on or stimulating the necessary investigations to enable the compilation of comprehensive manuals of practice on refuse collection and refuse disposal. The former manual will be a revision of a volume bearing the same title published by the APWA in 1941. The Engineering Research and Development Section,(2) Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio, is engaged in a joint study with the U. S. Bureau of Mines to investigate improved refuse incinerator design in order to develop design criteria which will provide satisfactory control of the discharge of atmospheric contaminants. The Taft SEC is also investigating how to improve small household-type incinerators.(9)

The American Society of Civil Engineers(2) has an active committee concerned with the preparation of a "Manual of Practice on Incineration of Municipal Refuse" which has proposed certain areas of incineration research. Two additional ASCE committees concerned in some part with refuse research include one committee organized to prepare a "Manual on Sanitary Landfill Practice" and a second committee working on atmospheric pollution. The Refuse Section(1) of the Research Committee of the ASCE Sanitary Engineering Division also is concerned with stimulating refuse engineering progress.

The Air Pollution Control Association(2) has a Technical Coordinating Committee T-2.1 with a Subcommittee interested in municipal incineration.

Weaver(3) reports that the United States Health Service, through the PHS Communicable Disease Center, is carrying on laboratory scale composting investigations at Savannah, Georgia, and landfill and field-type composting investigations and other refuse collection and disposal studies at Phoenix, Arizona.

Baity(4) states that the United Nations World Health Organization is planning to support a large scale night-soil disposal project in Japan. Composting will be the main system studied.

The California State Water Pollution Control Board,(9) under contract with the University of Southern California, is continuing an investigation of the effect of landfill refuse disposal on the production and travel of organic and mineral pollution in ground water.

Numerous municipalities(9) have investigated different phases of refuse handling and disposal in order to solve their local problems. For example, New York City,(9) has undertaken development studies that have resulted in new municipal incinerator design features. The City of San Diego, California,(9) has been able to increase the quantity of refuse that can be disposed in a given landfill area as a result of investigations of the addition of optimum quantities of water and the use of good compaction procedures. The City of Los Angeles(9) has been compiling data on the costs of operating a pilot refuse collection system. The Los Angeles County Air Pollution Control District(9) has performed numerous tests on the particulate matter and stack gases discharged by both small and large refuse incinerators.

New York University, New York City,(9) under a research contract is investigating how incinerator design may be improved. The Ford Foundation, through Resources for the Future, Inc., Washington, D. C., has supplied funds to Yale University(9) to enable an investigation of how waste materials such as organic refuse can be conserved to produce fertilizer and other products.

Westrate(5) reports that in the Netherlands the V.A.M., a government-supported organization, has pioneered in evolving an improved refuse processing system for converting organic wastes into either composted material

or disintegrated refuse; the latter product is used by local Dutch farmers as a heating manure. Studies on the carbon-nitrogen ratio and the effects of the disintegration of composted refuse on plant growth have also been investigated. A novel rasper mechanism for low cost grinding of these municipal waste end-products has been developed by V.A.M. and has subsequently been improved.

Need for Further Research

Our preliminary survey indicates that there is unanimous agreement on the need for further engineering research in the refuse collection and disposal field. Weaver(3) poses the question, "Why is refuse disposal research neglected?" Greeley(2) significantly implies that this neglect may in part be due to the need for added respectability and professional organization of the engineering of refuse systems. Eliassen(6) points out that it is perhaps the heterogeneous aspects of refuse collection and disposal that have inhibited rapid engineering development and make it one of the toughest problems which sanitary engineers must face. McGaughey(7) points out that there is a lack of sound, readily available, printed engineering information on refuse collection and disposal. Mallison(8) and others(1,3,9) have described a need for sound, overall local and nation-wide planning and the development of methodical, long-range refuse handling programs. The relative neglect of refuse engineering research and development can be summarized as being the result of a lack of appreciation by governing bodies and other agencies of the importance of good refuse disposal practices to both serve and economically protect the health and welfare of a community.

General Suggestions for Refuse Research

Weaver and Mallison believe there is still a need for a standardized nomenclature in the refuse field and additional work is suggested to clarify terminology. Greeley(2) suggests there should be an improvement of the methods available for financing refuse systems and that research studies should include the general considerations required for refuse system design. Mallison(8) suggests that an analysis should be made of the feasibility of using private enterprise under governmental agency supervision as a means of reducing the overall refuse disposal costs. As a minor point he notes that even prison labor may possibly be used for this latter purpose.

Weaver(3) states that there is a need for "a cooperative approach by interested national organizations, industry and government" and universities to develop comprehensive, orderly refuse sanitation programs. Weaver further points out that there are at present limited in-service training courses and inadequate teaching of refuse engineering fundamentals at American engineering schools. He also suggests the need for (1) development of standards and testing procedures for use in local codes for garbage and other refuse disposal, (2) practical solutions to refuse collections and disposal problems in urban renewal program areas, (3) basic research on new refuse engineering methods, and (4) a survey of existing state program responsibilities and legislation.

Costs

The need for cost data in refuse system planning is obvious. Weaver(3)

and Mallison(8) estimate, respectively, that the annual costs for refuse collection and disposal in the United States range from one-half to one billion dollars per year. Peters(15) believes that if a good determination of the direct and indirect costs of refuse collection and disposal were made, many communities would feel justified in upgrading their existing facilities. The expenditure of huge sums of money for refuse operations provides the opportunities for considerable savings through the development of improved refuse collection, handling and disposal practices.

Salvage

Research on the possibility of intensifying the integration of salvage practices with a collection and disposal system is suggested by Weaver(3) and Mallison.(8) The development of new salvage markets for employing refuse materials as an industrial raw material should not be overlooked. We have previously noted that the Ford Foundation, through Resources for the Future, Inc., has supported such an investigation at Yale University.(9)

Refuse Collection and Transfer

Schneider(10) suggests that a frank and unprejudiced study and report on the relative merits of compaction as against noncompaction types of refuse bodies is needed. These studies should reflect the advantages and disadvantages of all basic types of vehicles, including those that are unloading, side loading, rear loading, and top loading. Schneider(10) also recommends an additional investigation concerned with secondary haul vehicles as well as transfer facilities so as to ascertain more clearly when secondary haul is justified and what type of facilities and equipment would be most effective and efficient. Eliassen(6) and others(9,12,14) point out that there is a need for a routine compilation of data concerning the quantity and types of refuse at different cities and towns throughout the United States. Xanten(11) notes that the compilation of data on combined and separate solid waste collection systems and the costs involved are important for proper planning. Mallison(8) indicates that there is lack of sufficient information on fly-breeding control in the refuse collection system. Rogus(12) advises "That the APWA Committee has nearly completed negotiations for a program of sampling field and laboratory analysis in order to secure an accurate and authoritative picture on the pertinent physical and chemical characteristics of municipal refuse on a nation-wide, year-round basis."

Sanitary Landfill

Eliassen(6) believes that sanitary landfill is a well established practice with a thousand and one variations based on the characteristics of the refuse, the land, the equipment available, and the desires of the municipalities. Ingram(13) indicates that the effect of soil cover and the type of soil cover required for a landfill should be studied. Hendrickson(14) and others(9) are concerned about the effect and rates of CO_2 diffusion resulting from a landfill and it is suggested that this should be ascertained to determine the possibility of CO_2 causing ground water pollution. The amount of mineralization and hence ground water pollution resulting from sanitary landfill has been carefully investigated in California;(9) additional tests under other soil and climatic conditions appear warranted. Peters(15) believes that there is need

for further sanitary landfill fly emergence control investigations. Mallison[8] suggests a program of studies on economical operation of landfills for small communities. These studies would include a quantitative evaluation of the efficiency of excavation in various types of soil; a comparison of the efficiencies of different tractor appurtenances such as buckets; front-end loaders and blades; a comparison of basic equipment types, including crawler and wheel tractors; scrapers; cranes; drag lines; as well as the utilization of various combinations of these units and related time and methodology studies. Bowerman[16] and Mallison[8] indicate the desirability of further detailed investigations to reduce the cost of landfill by increasing compaction efficiency with water or by other means. The rates of decomposition of refuse and means of promoting such decomposition in a sanitary landfill should also be the subject of investigation.

Water Carriage

Bowerman[16] and Weaver[3] indicates that future development of refuse collection by use of a water carried system and grinding stations requires further research and development. Mallison[8] points out that refuse discharged into the sewer system may enable the future extension of our food resources by means of algal recovery to supply nutrients for plants and animal life.

Composting

Many of the authorities[9] contacted believe that composting is an interesting refuse processing system requiring further low cost development to achieve practical application in American municipalities. McGaughey[7] suggests that there should be further investigations on the extent of nitrogen losses and means of controlling these losses in composting. Mallison[8] believes that future mechanization of composting may improve the operational and cost picture. Peters[15] recommends additional applied large-scale research in composting solid wastes to develop methods of controlling fly, rat and odor nuisances.

Incineration

Eliassen[6] suggests that there is a need for further investigations concerning the phenomenon of combustion and that, in general, it may be desirable for sanitary engineers to work with mechanical engineers to develop and improve incinerator combustion systems. Schneider[10] and Xanten[11] both have expressed a need for improved incinerator design criteria for flues and expansion chamber capacities in order to improve stack gas discharges and thereby air pollution. Mallison[8] mentions that there is need for an improved small incinerator and Overman[17] recommends development of incinerators capable of handling garbage and other combined refuse.

There is a general recognition among all the authorities queried that there is further research required concerning: the air pollution effects of incineration, reducing the cost of incineration, and improving the efficiency of incinerator operation.

Animal Feed and Ocean Disposal of Refuse

Mallison[8] indicates that further research is desirable for improving the

utilization of garbage supplied as animal feed. He also believes that disposal of refuse products into ocean and other water bodies may have certain limited applications.

Conclusions

1. Present refuse engineering research investigations appear to be neglected, fragmentary and inadequate for the orderly development of this major sanitary engineering field.
2. All authorities within the refuse engineering fields expressed the need for further specific research and development programs.
3. General suggestions for improved refuse engineering programs include: (a) nomenclature standardization, (b) improvement of methods to finance and design refuse handling systems, and (c) above all, an orderly local and national program to promote the research, development and organization of the refuse engineering into a well respected, technical activity.
4. Additional detailed refuse operation cost data is needed. It is estimated that the refuse disposal and collection costs in the United States are about 0.5 - 1.0 billion dollars a year. Improved refuse engineering practices may save money and upgrade service.
5. The development of larger salvage markets for refuse remains a challenge.
6. Research is needed to improve the collection vehicles and secondary transfer facilities as well as to ascertain the quantity and quality of refuse produced.
7. Further landfill refuse disposal research is needed to determine optimum low-cost systems for (a) maximum refuse compaction, (b) materials handling equipment, (c) accelerating landfill decomposition, (d) improving sanitary control of flies and other nuisances and (e) the effect of landfill operation on CO_2 production as well as other possible causes of mineralization and ground water pollution.
8. Composting requires further development to obtain a low-cost and improved system of operation.
9. Improved incinerators are needed to reduce costs, improve stack gas quality, and in general to improve their combustion characteristics and ability to handle garbage and mixed refuse.

Acknowledgment

The Refuse Section of the Research Committee of the S.E.D., ASCE, wishes to thank all the individuals who have so generously cooperated in providing the supply of ideas presented in this paper. In part, acknowledgment is made of certain of these authorities in the appended "Bibliography of Correspondents."

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SOME ENGINEERING ASPECTS OF HIGH-RATE COMPOSTING

John R. Snell,[a] M. ASCE
(Proc. Paper 1178)

SYNOPSIS

One of the least known methods of garbage and refuse disposal, composting, is currently being considered as an important means of conserving natural resources as well as of disposing of solid wastes. A discussion of the factors affecting high-rate composting is given to give the engineer a better understanding of the fundamentals of composting.

INTRODUCTION

This article attempts to gather together such information as is readily available on high-rate composting which may be of interest to the engineers. It is hoped that it will stimulate others to further test whatever conclusions may be drawn from the data presented and that in this way more reliable conclusions will result.

For the most part the information presented here is not the original work of the author but it taken from published data from four composting research projects each costing well over $100,000. The original project by the University of California was followed by one at Michigan State University. Research is being continued with two projects by the U. S. Public Health Service. Other information came from a literature survey, and some of the more practical aspects from the consulting work of the author.

The opinions expressed in this article are the personal thoughts of the author and in no way reflect any thoughts or opinions of the administration of Michigan State University, where the author was formerly Head of the Department of Civil and Sanitary Engineering and was the initiator and co-director of the High-Rate Composting Project.

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Previous Experimental Work

Two years of laboratory and windrow composting research were reported at the University of California by McGauhey and Gotaas.(1,2) About the same time pilot plant work was conducted in New Zealand. This work, reported in November-December, 1951, issue of New Zealand Engineering, concerns itself mostly with windrow and bin-type batch composting.(3) The most recent comprehensive published research paper reports the laboratory scale batch composters of the U. S. Public Health Service Laboratories in Savannah, Georgia.(4) Other experimental results which should be mentioned include a Master's thesis by Gordon Ludwig(5) and results of George Mallison, Sanitary Engineer, U.S P.H.S. Experiment Station in Phoenix, Arizona. The Michigan State University research work is available locally in published form in two preliminary mimeographed reports to the National Institute of Health,(6,6a) three Master's theses and one Ph.D. thesis.(7,8,9,10) Further experimental data which are as yet unpublished and considered confidential are from work done by three commercial groups. Two groups are interested in producing compost(11,12) and one in developing a modern digester.(13) Three unpublished preliminary reports for the City of Kobe, Japan on their high-rate continuous flow pilot plant give results on the composting of garbage and "Night Soil."(14) As a consultant, sponsored by the World Health Organization, the author has assisted in this pilot research and in the design of their first full scale high-rate composting plant.

The value of organic material to the soil for production of greater and more valuable crops is a subject of importance to anyone interested in composting. Extensive work has been done in this field; yet before accurate dollar values can be placed on organic material in the soil a great deal of further experimental work will be required. A literature survey on this subject covering 120 references and five languages was conducted at Michigan State University.(15)

Some recent work on the practical phases of composting has been conducted in England by Hal Guthredge(16) and J. C. Wylie.(17,18,19) Large scale composting work in Holland for some years should be mentioned.(20) Attention should also be called to the practical composting experimental work done in Australia.(21)

Pilot windrow studies of municipal garbage in San Diego, California, are reported by the Sanitary Engineering Division of the American Society of Civil Engineers.(22)

Comparison of High-Rate Composting with Conventional Processes

In order that the engineer might have a basis for comparison with methods and processes familiar to him, high-rate composting might be compared to anaerobic sludge digestion and to the activated sludge process. The comparison with conventional methods may seem unfair because composting takes place with organic matter in a much more concentrated form than does conventional sewage sludge; however, it does give some basis for evaluating the composting process.

Anaerobic Sludge Digestion versus Composting

For digestion at 90°F. (25 days detention) mixed primary and activated

sludge require a minimum of 1.0 cu. ft. of digester capacity per capita or 100,000 cu. ft. for that same population. The per capita sludge gas production is about 1.25 cu. ft. per day and about 0.50 cu. ft. of this would be required to heat the digestion tanks themselves. Estimating 650 BTU's per cu. ft. for sludge gas—the value of the 0.75 cu. ft. of excess gas per capita per day is 0.049 cents (based on an average commercial rate for natural gas with 1,000 BTU's cu. ft. and costing 10¢/100 cu. ft.). For 100,000 people the excess gas is worth about $50 per day or $18,000 per year.

For high-rate composting the same quantity of sludge dewatered to 55-60% solids in a highly porous condition would weigh about 30-35 lb./cu. ft. and would occupy only about 0.015 cu. ft. per capita or 1,500 cu. ft. per 100,000 population. For a four day composting digestion cycle 6,000 cu. ft. or only 6% of the storage volume required for anaerobic digestion is required.

The value of the end product (at $20 per ton with 20% moisture) is $\frac{1,500 \times 32.5 \times 42.5}{2,000 \times 80.0} \times \$20 = \$260$ for the 13 tons produced per day or $95,000 per year. These figures are given only to show that the loss of gas production in switching from anaerobic digestion to composting is compensated for several times over by sale of the end product. The relative cost of operation should be comparable and capital cost of the plants should be considerably less for the high-rate composting.

Activated Sludge Process versus Composting

Although the conventional high-rate composting process is adaptable only to porous solid wastes a comparison to the activated sludge process will be valuable to the engineers, especially those who would advocate "burning up" of most of the organic matter in the aeration tank and omitting the final sedimentation tank.

Since the rate of flow of air greatly affects any activated sludge figures, three rates 6, 12, and 18 cu. ft. per minute per 1,000 cu. ft. of volume have been selected. Figures are calculated from Mr. H. R. King's article[23] and are for a 10% air diffuser plate area and a 15 ft. depth. Power figures are based on a 65% compressor efficiency and 1.25 lb. line loss.

For the high-rate compost process, calculations are based on a 4 ft. depth of material with forced air (3" water head loss). Optimum moisture content of 55% is used with an 0_2 utilization rate of 0.0244 grams 0_2 per 100 grams dry weight per minute or 366 lbs. oxygen per hour per 1,000 cu. ft. (at 25 lbs. compost cu. ft.) The calculation also assumes 50% oxygen utilization from the air.

Four methods of comparison are made in Table 1. (See page 4)

From a study of Table I it is evident that the power requirements of composting are 1.0-1.5% of that for activated sludge and that the rate of oxygen utilization on a volume or ppm basis is 100 to 300 times as great. Oxygen utilization on a dry solids weight basis is very comparable however.

These comparison values are given only to stimulate interest in the possibilities of the high-rate composting and are not given as design criteria.

Description of M.S.U. Experimental Facilities[6,6a]

The various phases of the M.S.U. composting research, although closely correlated and inter-related, were separated into three general areas.

Table 1. Comparison of Activated Sludge Process with High-Rate Composting

	Air Flow Rate CFM/ 1000 cu. ft.	Activated Sludge Process	High Rate Composting	Comp. Ratio: Act. S.
Watt Hours Power per pound O_2 Absorbed (22)	6	140	Without Stirring	.009
	12	160	1.2	
	18	170	With Stirring 2.5	.015
Oxygen Absorbed ppm/hour	6	23		290
	12	40	6,600	165
	18	55		120
Oxygen Absorbed lbs/hr/1000 cu. ft.	6	1.4		260
	12	2.5	366	150
	18	3.5		105
Oxygen Absorbed lbs. O_2/100 lbs/ hour	3000 ppm (at 12 CFM)	.004	(55% Moist) .66	165
	Dry wt. (at 12CFM)	1.33	dry wt. 1.46	1.1
	% of dry wt/ day (at 12CFM)	32%	% of dry wt/day 35	1.1

(1) Basic laboratory research, (2) Experimental continuous flow pilot plant, (3) Experimental windrow composting. A description of the pilot plant was given by the author in an earlier article.(35) It will suffice to say here that the pilot plant consisted of a large grinder, a storage tank and an 8 level, 10 ft. diameter vertical type digester modified, for research purposes, from the basic Earp-Thomas type design. The plant started by using the storage hopper as a crude dewatering tank for the raw garbage and ended by employing a continuous flow dewatering press. The rather unsatisfactory bucket conveyor was replaced with a screw and a tubular conveyor. The plant, under satisfactory operating conditions, handled 3 to 5 tons of ground separated domestic garbage daily. A proto-type Crane digester of about 1/2 ton per day capacity was tested and improved over a nine month period. Except for mechanical breakdowns and mechanical changes the pilot plant ran from July 1953 until September 1955 and during these periods the 3-5 tons/day of separated domestic garbage from East Lansing was handled at the plant.

The windrow operation(9,36) included three main areas of interest; (a) composting of ground garbage in air tight insulated 50 gallon drums in which the material was removed and shredded periodically, and in which air flow was recorded, and oxygen utilization and carbon dioxide production and other measurements and tests were conducted, (b) small outdoor windrow piles of about 1-4 cu. yards, (c) composting in windrows of about 300 tons of garbage using a front-end loader and a large shredder. Oxygen and carbon dioxide studies were made with probes and control tests run on both these series of experiments.

The basic laboratory studies(6,6a) were designed after some understanding of composting was gained from preliminary windrow and pilot plant studies. The resulting laboratory unit is illustrated in Figure I and was designed to give constant stirring (1/5 r.p.m.) under constant and controlled conditions. Twenty-two of these one pound plastic digesters were constructed in early 1954 and have been used in many series of experiments. In addition to oxygen utilization and carbon dioxide production measurements, many other chemical and bacteriological tests were run to determine the rate and degree of aerobic decomposition at various temperatures and moisture conditions.

The laboratory studies also included studies on permeability(8) and the rate of diffusion of oxygen into ground garbage under various conditions.(10) Also included was a special emphasis on determination of suitable yardsticks and basic bacteriological studies.(7)

The basic laboratory phase has been supported by the National Institute of Health in the amount of a total of $30,000 during the two years 1954 and 1955 and is continuing into 1956. This work was accomplished by a team of chemists, bacteriologists and sanitary engineers including three doctorate candidates and five master's candidates* and a number of other part time students.

In addition, four Master's candidates undertook research without N.I.H.

* B. J. Shell (Sanitary Engineer 1/2 time grad. asst.) Ph.D. Dec. '55; Robert Lipe (Chemist 3/4 time grad. asst.) Ph.D. in progress; Fred Weber (Bacteriologist 1/2 time grad. asst.) Ph.D. in progress; W. G. Turney (Sanitary Engineer 1/2 time grad asst.) Master's Thesis June 1954; Shi-Who Kao (Sanitary Engineer 1/2 time grad. asst.) Master's Thesis Dec. '54; John Zondorak, Chang Moon Beck and William Hohlock.

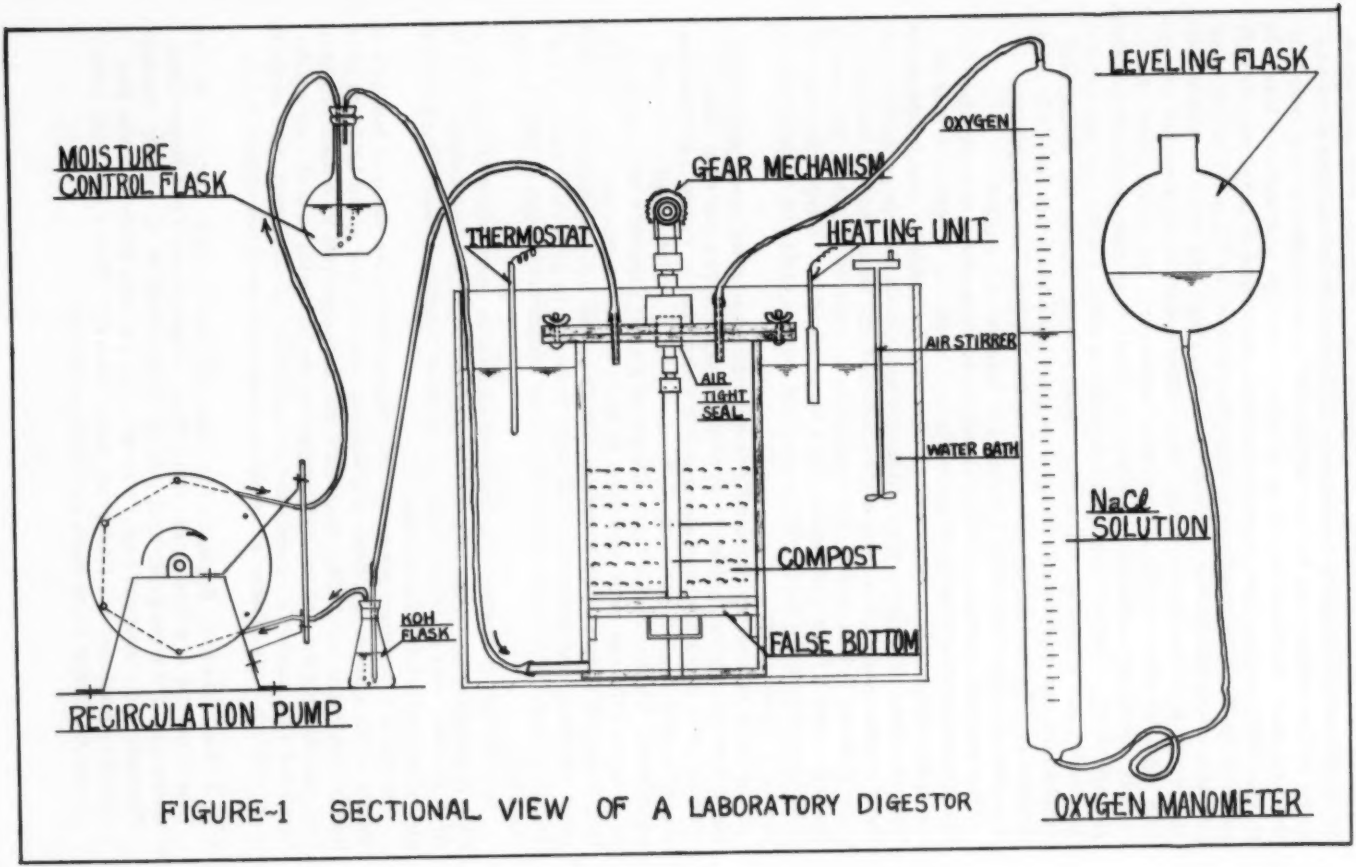


FIGURE-1 SECTIONAL VIEW OF A LABORATORY DIGESTOR

support in various related aspects of composting.** The work was done under the joint general supervision of the author and Dr. Robert F. McCauley. Dr. W. L. Mallmann, Professor of Microbiology directed the bacteriological phase and acted as an overall consultant. Acknowledgment is made to each of these men for his contribution to engineering phases of the research work.

Essential Criteria to Obtain Maximum High-Rate Composting

In order that an organic waste material may be stabilized rapidly (2-4 days) the following criteria are considered, by the author, to be essential:

a) Material should have a C:N ratio of 50:1 or less and have no serious deficiency of essential foods and be within normal pH range (5.5-8.0).
b) Material should be finely ground.
c) Moisture should be controlled to 50 to 60% throughout the process.
d) Recycling of seed compost (2-10% of very active partially composted material).
e) Constant slow stirring or intermediate stirring every 5-10 minutes.
f) Air should reach all parts of the composting material with at least 50% of the oxygen remaining.
g) Temperature should be controlled throughout the process.
h) The pH should be prevented from going too high to prevent nitrogen loss.
i) The process should be continuous flow in 3 or 4 stages including recycling of seed and thorough mixing for each stage. The last stage may combine slower digestion with natural drying from the produced heat.

It should be understood that complete breakdown does not occur during this period of 2-4 days. The putrescible protein and the sugars and a considerable proportion of the starches will break down leaving, almost untouched, the cellulose, woodfiber, lignin and other resistant materials. There may, however, be no need for further breakdown. Further decomposition can, in most instances, be accomplished more advantageously in the soil where plant growth will be benefited by the presence of soil organisms and by the end products of their metabolism.

Variables Studied and Those Requiring Further Study

Those who have had some experience with composting research will appreciate the difficulties in studying a dozen or more variables when the essentials of the overall process are not fully understood. It may be 10-20 years before there has been enough work to thoroughly understand the many variables and their relationship with one another. The difficulty of research becomes more obvious when it is stated that as far as is known all of the major essentials of high-rate composting have yet to be reproduced in a laboratory scale experiment.

The reason for this is the difficulty in handling, feeding, removing and measuring small quantities of ground, moist, solid organic material on a continuous flow or even an intermittent flow basis. Thus the M.S.U. laboratory digesters were of batch type. The only true high-rate experiments were conducted in the pilot plant when it was operated under controlled conditions

** Reginald Batzer, Samuel Maiore, Carl Billings. All Sanitary Engineers.

and fully backed by the whole laboratory research personnel. The laboratory work was not true high-rate composting because batch runs have all the lag periods for bacterial population buildup for each stage. Even with this serious limitation the lab experiments were the most important phase of our research.

Of the twelve variables listed for study only two have been pursued intensively. These are: (1) effect of percent moisture and (2) effect of temperature on the rate of composting. These will be discussed in some detail in succeeding paragraphs. Other variables, yet to be as scientifically explored, are discussed briefly as follows:

(3) pH: Normally, raw garbage is rather acid, pH 5.0-6.0. Although aerobic digestion proceeds reasonably well at this pH, adjustment to a slightly high pH gives evidence of speeding the process. As garbage digests the pH slowly rises until at the end of the process it reaches pH 8 or even 9. High pH conditions and high nitrogen content will generally result in a substantial nitrogen loss. It is believed this loss can be prevented by controlling the pH and insuring an ample oxygen supply.

(4) Oxygen Supply: It is rather well accepted that only part of the oxygen required for digestion comes from the atmosphere and the remainder is obtained from the breakdown of organic compounds themselves. It can be readily demonstrated, however, that the process is greatly retarded by lack of the presence of some gaseous oxygen at all times. Without almost continuous movement of the digesting mass or forced air or both movement and forced air, it is practically impossible to fulfill this condition.

(5) Carbon Dioxide Build-Up: The importance of a high percentage of CO_2 in contact with the digesting mass has been pointed out by Eric Eweson but has not, as yet, been substantiated by others' work.

(6) Ratio of Carbon to Nitrogen: The importance of the ratio of carbon to nitrogen has long been understood and was recently substantiated by the University of California experiments. The importance is seen when it is understood that the nicroorganisms need the nitrogen to build up their population and that they need the carbon for energy. Waksman points out that a ratio of carbon to nitrogen of 30:1 is ideal for most microorganisms. As digestion proceeds carbon is converted into carbon dioxide and liberated whereas, nitrogen is stored in the protoplasm of the bodies of living organisms. If the conditions are not ideal and too much nitrogen is present some of it may be lost as nitrogen gas or as ammonia. When soil is mixed with a completed compost with a carbon nitrogen ratio of 20 or less the compost should not temporarily rob the soil of its natural nitrogen. Generally richer wastes with lower carbon nitrogen ratios, say 50 or less, compost more rapidly than those with a higher ratio, say 50 or greater. The effective ratio of carbon to nitrogen controlling the rate of composting does not necessarily represent a carbon nitration ratio for the mixture as a whole but is more likely to represent the ratio in the material more readily digested.

(7, 8, 9) Deficiencies in essential foods, fineness of grind and uniformity of mixing are all obviously important points to those understanding biological decomposition and will not be further commented on at this time. It will be some time yet before these finer points can be thoroughly investigated and evaluated. The effect of fine grinding is to speed up the process in that such grinding gives the microorganisms more surface area on which to grow. However, as will be seen later, fine grinding cuts down the porosity and thus the supply of oxygen through the material.

(10, 11, 12) Seeding and Reseeding; Batch or continuous flow; and Stirring or Stationary: With the limited data yet available these three subjects might best be lumped together for a brief general discussion. Although it has been demonstrated by both the University of California and Michigan State University that composting can be very satisfactorily accomplished without employing any special seeding cultures, it has not, however, been completely established whether these cultures do or do not have some merit. There is evidence to show that there is tremendous value in the inoculation of the raw garbage with substantial quantities of partially processed material in which the desired organisms are already predominent. Likewise, the marked rapidity of a continuous flow process as compared with the batch process has been demonstrated. Again, continuous or frequent intermittent stirring or mixing has an accelerating effect on the process. It is believed these phenomena can best be explained by the following hypothesis: The seeding and reseeding and the stirring which occurs in a continuous flow multistage process largely eliminates the lag periods required for the various biological populations to build up in the batch type of process. In each stage of digestion the physical and biochemical environment may be kept at an optimum and large masses of the most desirable microorganisms are present and continuously brought into contact with a supply of fresh food from the preceding stage of digestion. Thus the same work accomplished in a 2-3 week batch process can be effected in a 2-4 day continuous flow multistage stirring process if the proper environment is maintained and seeding and reseeding are practiced.

Yardsticks to Measure Degree and Rate of Composting

One of the present handicaps to the compost researcher today is the lack of an adequate yardstick for digestion. Men, long associated with the art of composting, have depended upon appearance, odor and feel of the end product to determine whether or not it has been properly composted. More scientific yardsticks are essential. It is not desirable to carry the digestion process too far because less organic material will then be available for enrichment of the soil. However, it is desired that the material be stabilized to the extent that upon being remoistened and piled (1) it will not over-heat (2) lose appreciable nitrogen (3) become offensive. The exact point during the digestion process at which all of these criteria are fulfilled is difficult to determine for routine work. It becomes highly desirable that a test be developed which can readily show exactly how far the digestion process has proceeded. Because of the wide variation in the nature of materials to be composted it is possible that no single criteria or yardstick can be used for all organic wastes.

For example, the change of pH during the normal course of digestion of garbage or animal manure from about pH 5-6 to 8-9 has proven to be a very useful yardstick. Other wastes with a high initial pH of about 8 have almost no change so under these conditions pH is useless as a yardstick. The most useful recommended yardstick for measuring the degree of composting are given in Table 2.

Oxygen consumed and ash are considered the best primary practical yardsticks for degree of digestion, although pH and transmittance are good quick indirect methods when used as a routine control where their relationship with

Table 2. Summary of Yardsticks to Determine Degree of Composting as Applied to Ground, Separated Garbage

Test	Used	Raw	Finished	Reliability
1	pH	5.0-6.0	8.0-9.0	Only indirectly related & not reliable
2	Chemical Oxygen Demand	-	-	85% reduction
3	Oxygen Consumed	-	-	25% reduction
4	Ash	10%	20%	Difficulty in obtaining representative samples
5	% Transmittance (6a)	70%	10%	Only indirectly related. Not reliable

other yardsticks have been previously established. COD is a useful yardstick but is more time consuming and offers certain laboratory problems.

The following four tests were tried by Mr. W. G. Turney but developed technical difficulties not readily overcome and until further work is done are not dependable yardsticks: (a) relative stability (b) BOD (c) chlorine demand (d) iodine demand.

Other less scientific but commonly used tests are (a) appearance (b) odor and (c) generation of heat.

During the composting process the material changes from a brown to a black and from a fibrous to a friable appearance. The odor of raw garbage may vary from rancid to putrid while that of well composted material has a slightly earthy or sometimes musty odor. Generation of heat as a yardstick is unreliable and depends on the degree of oxygen available, insulation, seeding, % moisture, pH, time, surrounding temperature, etc. It is possible that these variables may be studied and a reliable controlled test result but no definite conclusions should be drawn from this test at present. All but very old compost material will reheat. To carry the digestion process to the point where reheating will not occur may be impractical and perhaps undesirable. Development of a reheating test may also prove to give a quantitative answer on the momentary rate of digestion.

Yardsticks for rate of digestion which have proven useful are (1) oxygen utilization and (2) carbon dioxide production. For these yardsticks to be used on pilot scale of plant work may require the removal of a representative sample to a laboratory size digester where standard temperature can be maintained and adequate, continuous stirring provided. These two yardsticks have been the main method of measurement employed in most of the M.S.U. research. Carbon dioxide produced in these experiments was absorbed by bubbling through caustic before the oxygen utilization was measured directly

by reduction in volume. The oxygen measurements are rather easy to make at frequent intervals whereas the carbon dioxide production requires titration of the caustin solution and replenishment each time. Unless this is done with utmost care, inaccurate results may be obtained.

On plant scale experiments oxygen uptake and carbon dioxide production can be reasonably well estimated by making air flow measurements and also frequent analysis of the exhaust gases. Such a procedure, when practical, is strongly recommended as a control in the operation of full scale plants.

Effect of Moisture(6)

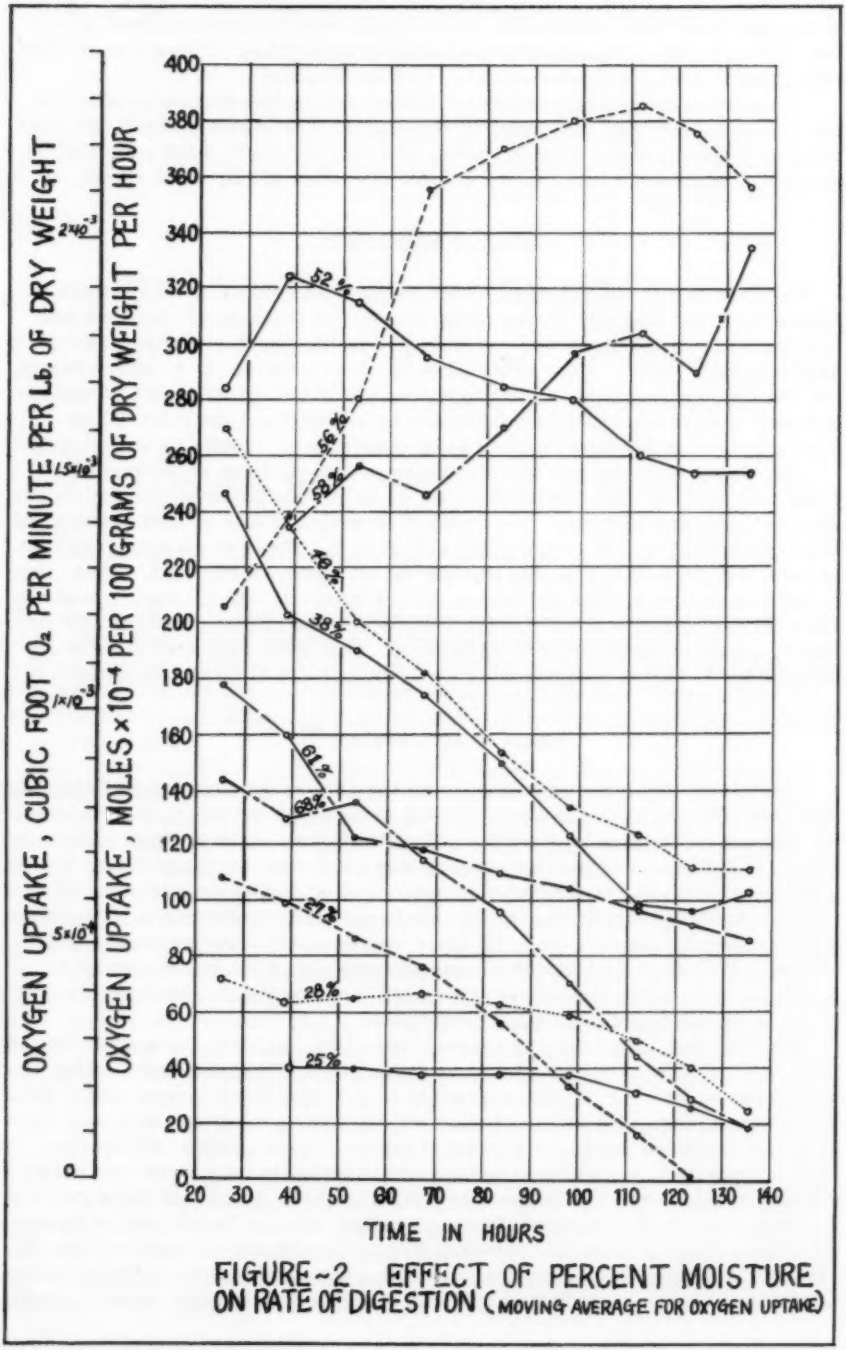
When the M.S.U. experimental work began it was known from the work of others that moisture was an important factor; yet little was it realized how critical a factor moisture was and how narrow the moisture range was for peak digestion rates. If the material is too dry—insufficient moisture exists for the metabolism of the microorganisms and if the material is too moist—the pore spaces are filled, the surface area reduced and the material becomes anaerobic because oxygen cannot penetrate as rapidly as it is required.

Ten M.S.U. experiments on composting ground garbage at moisture contents varying from 25% to 68% were set up in the one pound laboratory digestors and run for 140 hours. The rates of digestion of this ground garbage for each percentage moisture are given in Figure 2. These same data replotted as total oxygen taken up during this period are given in Figure 3. These two figures show that for this particular type of material that is ground, separated, domestic garbage at 40° C. batch digestion, the optimum percent moisture lies in a narrow range of 52 to 58 percent. This work explained many early difficulties at M.S.U. in attempting to digest garbage at 70 to 80% moisture.

Effect of Temperature(6)

Laboratory digestion experiments during 1955 at Michigan State University included a series of ten studies designed to measure the effect of temperature on the rate and degree of digestion. The limitations of these experiments include (1) the batch composting process was employed, (2) temperature was kept constant during all stages of digestion, (3) at higher temperature (65 and 70 degree centigrade) it was impossible to maintain a percentage of moisture satisfactory to good digestion, (4) there was no seeding and reseeding procedure followed so as to develop optimum organisms for any temperature level. Despite these limitations it was felt that results obtained may be of value to the engineer and future researcher.

Ten different temperatures ranging from 25°C. to 70°C. were investigated. The results of these experiments are presented in Figures 4 and 5. The points shown on these figures represent an average of the oxygen uptake data from the two laboratory digesters held at each designated temperature. In so far as possible the moisture content of these units was held at 56 plus or minus 2 percent. It was found impossible to maintain the proper moisture content at the 65 and 70° temperature experiments. A study of these two figures indicates that comparatively good digestion can be obtained at temperatures ranging from 35°C through 60°C. Temperatures ranging from 40 through 55 appear to be considerably better, however, and the optimum temperature, at least, as indicated by these experiments, appears to be at about



FIGURE~2 EFFECT OF PERCENT MOISTURE ON RATE OF DIGESTION (MOVING AVERAGE FOR OXYGEN UPTAKE)

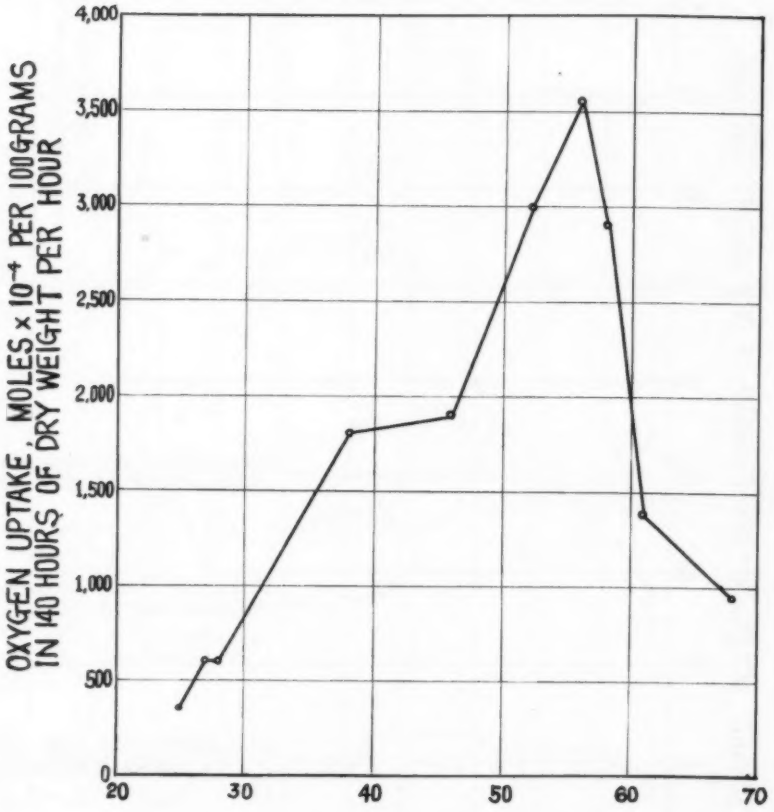


FIGURE-3 TOTAL AVERAGE AREA UNDER EACH OXYGEN UPTAKE CURVE AT VARIOUS MOISTURE CONTENTS

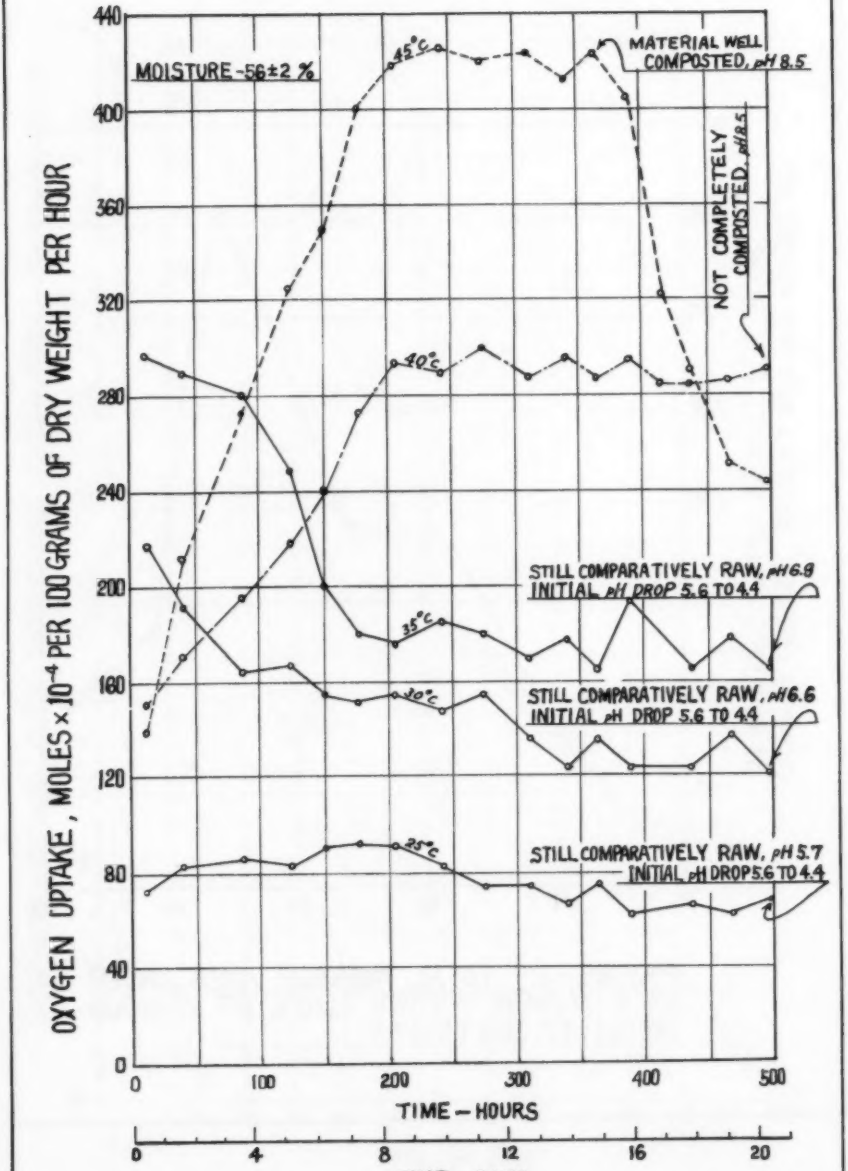
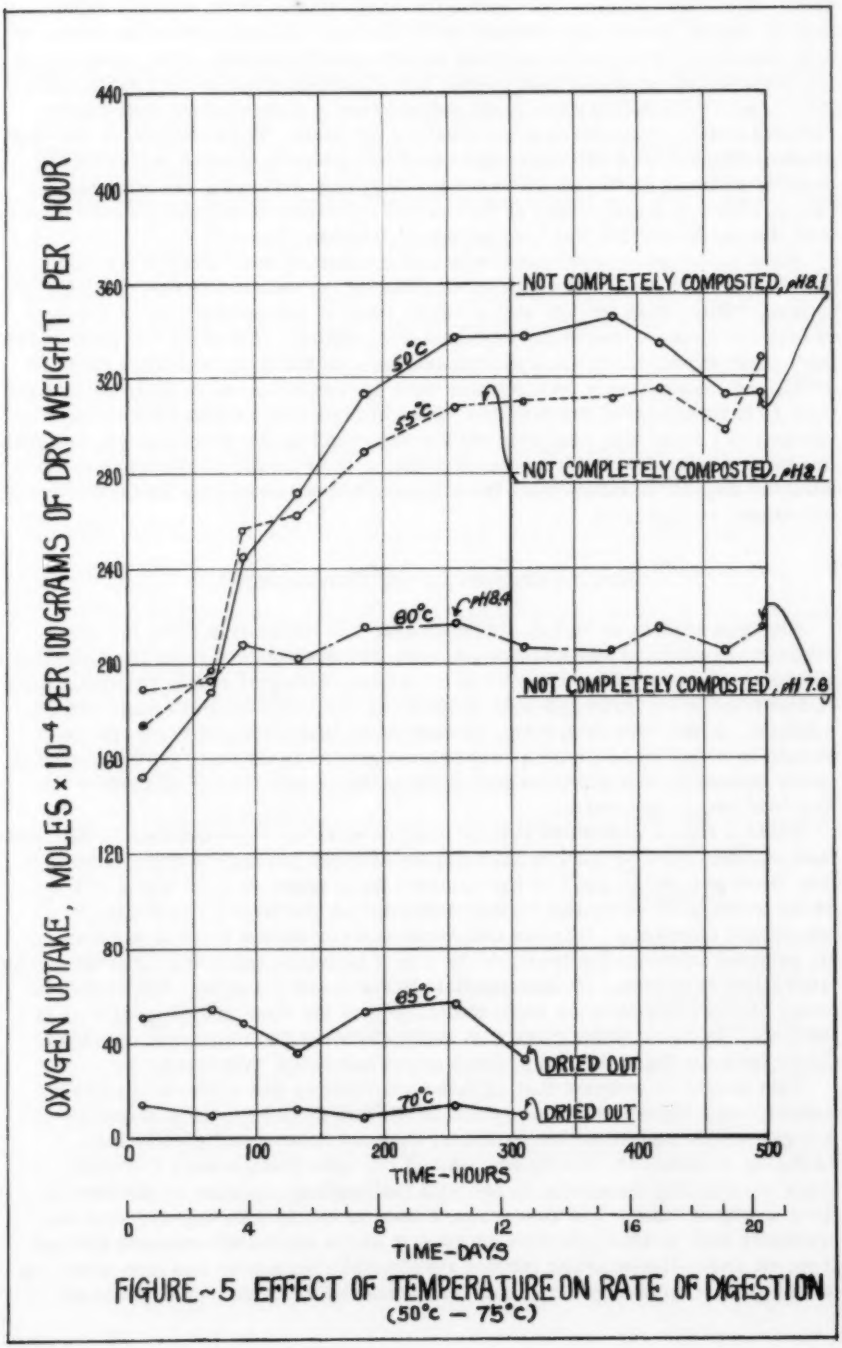


FIGURE-4 EFFECT OF TEMPERATURE ON RATE OF DIGESTION
(25°C – 45°C)



FIGURE~5 EFFECT OF TEMPERATURE ON RATE OF DIGESTION
(50°c – 75°c)

45°C. It should be noted that during the early stages of digestion a higher rate of oxygen uptake was obtained at 35 degrees indicating that the initial or acid stages of digestion has a lower optimum temperature. The initial pH of the material at all temperatures was 5.6. The experiments held at 25, 30 and 35°C. had a high initial drop to pH 4.4 and then a slow rise but they never reached what is considered a satisfactory pH level. The condition of the end-product at the end of 500 hours and of pH are given in the two figures. The experiments run at 40 and 45° were the only ones following the normal pH curve, although experiments at 50 and 55° followed the normal pH pattern with the exception that the final pH was 8.1 rather than 8.5.

When these batch type experiments at a constant temperature are compared with the pilot scale experiments employing continuous flow, multistage type operation, it is evident that a single level of temperature does not represent optimum condition for high-rate composting. Digesting material in the pilot plant experiments showed temperatures on the first two decks of 30 to 35°C. and rising slowly on the lower deck to temperatures of 60 to 65 and appear to have produced much higher rates of digestion. Other factors such as seeding and reseeding may overshadow the effect of the temperature changes; however, a great deal more experimentation is necessary before one can say with any degree of surety what the optimum temperature may be for the various stages of digestion.

Nitrogen Changes During Composting(6)

Nitrogen studies at M.S.U. included over 750 qualitative tests for the presence of nitrates and nitrites and over 300 quantitative tests for ammonia and total nitrogen. These were run on the raw material and in various stages of digestion in all three types of composting: laboratory, pilot plant and windrow. Some very interesting results have been obtained yet more research is required to conclusively determine and understand the phenomenon of the partial loss of nitrogen during the process and also to determine how this loss can be prevented.

Table 3 shows where nitrates or nitrites were or were not found. Nitrates and nitrites were present in all samples of fresh garbage tested. Likewise they were present in 100% of the samples from upper decks 1 and 2 of the 8 decks in the pilot plant and were present during the first 48 hours in the laboratory digesters. Nitrites and nitrates were absent 100% of the time in all samples taken on the lower decks 5 to 8 inclusive and after 70 hours in the laboratory digesters. On intermediate decks 3 and 4 and between 48 and 70 hours nitrites and nitrates were absent part of the time and present part of the time. In the windrow piles they were absent in the actinomycetes layer (layer between 2 and 4") and present above and below this layer.

This seems to indicate that nitrates and nitrites are either utilized biologically at a higher rate than produced or that the composting material, although aerobic and an active oxidizer, does not have a sufficiently high oxidizing potential for nitrifying reduced nitrogen compounds. Certainly these composting materials do not hold the existing nitrates or nitrites in their oxidized state. The raw garbage used in the M.S.U. experiments was unusually high in total nitrogen because it was a separated wrapped garbage from an above-the-average income residential community and also often contained quite a number of dead chickens from the Agricultural Experiment

TABLE 3

The Presence or Absence of Nitrates or Nitrites During the Composting Process

Sample Type and Location	Number of Tests	Nitrates or Nitrites Present or Absent
Raw garbage	60	Present
Drain fluid from Raw garbage	55	Present
Garbage at top of Dewatering tank	50	Present
Garbage at bottom of Dewatering tank	50	Present
Drain Fluid from Dewatering tank	50	Present
Digester - Deck 1	30	Present
Digester - Deck 2	30	Present
Digester - Deck 3	30	Absent 5 times Present 25 times
Digester - Deck 4	30	Present 11 times Absent 19 times
Digester - Deck 5	30	Absent
Digester - Deck 6	30	Absent
Digester - Deck 7	30	Absent
Digester - Deck 8	30	Absent
Windrow compost - layer above Actinomycetes layer	20	Present
Windrow compost - layer containing Actinomycetes	20	Absent
Windrow compost - layer below Actinomycetes layer	20	Present
Laboratory digester - start	10	Present
Laboratory digester - 6 hrs. after start	10	Present
Laboratory digester - 18 hrs. after start	10	Present
Laboratory digester - 30 hrs. after start	10	Present
Laboratory digester - 47 hrs. after start	13	Present 10 times Absent 3 times
Laboratory digester - 59 hrs. after start	13	Present 1 time Absent 12 times
Laboratory digester - 71 hrs. after start	10	Absent
Laboratory digester - 122 hrs after start	10	Absent
Laboratory digester - 207 hrs after start	10	Absent
Laboratory digester - 336 hrs after start	10	Absent

Station. Total nitrogen tests on the raw material varied from a low of 3.0% to a high of 8.0% with an average of 6.3% (on basis of total dry solids). Ammonia nitrogen of the raw material varied from .25 to .40%.

Figures 6 and 7 show the total and ammonia nitrogen values in the pilot plant and in a typical laboratory digester respectively.(6) From a study of these curves it would appear that if a high initial total nitrogen is to be maintained the pH will have to be held at either below or at about pH 5.0. It is also quite evident that a medium level total nitrogen content of about 3.0 percent can be reasonably maintained at pH values of 8.0 to 8.5. Other experimenters show no loss of nitrogen while composting mixed garbage and trash with 1.7% total nitrogen despite a rise in pH from 4.8 to 8.4.

It is quite likely that with inadequate aeration the total nitrogen content, during composting, cannot be held above 1.0 to 1.5%.

The relatively low values of ammonia nitrogen observed in the M.S.U. experiments (0.25 to 0.5%) probably represent only a transition stage, and if ammonia concentrations become larger it is lost to the atmosphere. Although by no means conclusive, it would appear that total nitrogen above about 3.% will be lost during composting unless the pH can be held below about 5.0-6.0. This can perhaps be accomplished by adding sulphur dust at the right stages or by the addition of trash to lower the percent of total nitrogen. It may also be practical to collect the lost nitrogen by passing the exhaust gases through an acid filter or scrubber. Carbon determinations as such were not run as controls on M.S.U. experimental work. For those accustomed to thinking in these terms, a rough approximation can be had by use of the following formula:

$$C = \frac{100 - \% \text{ ash}}{1.8}$$

Thus during composting the average raw material with 10% ash, 6.3% nitrogen calculate to have a C/N value of 8.0 while the final product with 20% ash and 3.0% nitrogen calculates to have a C/N value of 15.

The C/N ratio required so as not to temporarily rob nitrogen from the soil and thus reduce crop yields is estimated to be about 20:1.

Preliminary Carbohydrate Studies(6)

Carbohydrate breakdown during the composting process has been studied at M.S.U. on a qualitative basis only. Tests have been made to determine the presence or the absence of cellulose, hemicellulose, starch, disaccharides and monosaccharides. The results of this study are given, along with the nitrogen values, in Table 4.

It appears that the high-rate composting process does not cause much breakdown of the cellulose but most of the disaccharides and monosaccharides (soluble sugars) disappear quickly and are probably the chief cause for the initial lowering of the pH. Although the qualitative chemical test indicates that starch disappears rather quickly, a microscopic examination indicates that some starch grains remain to the end of the digestion period.

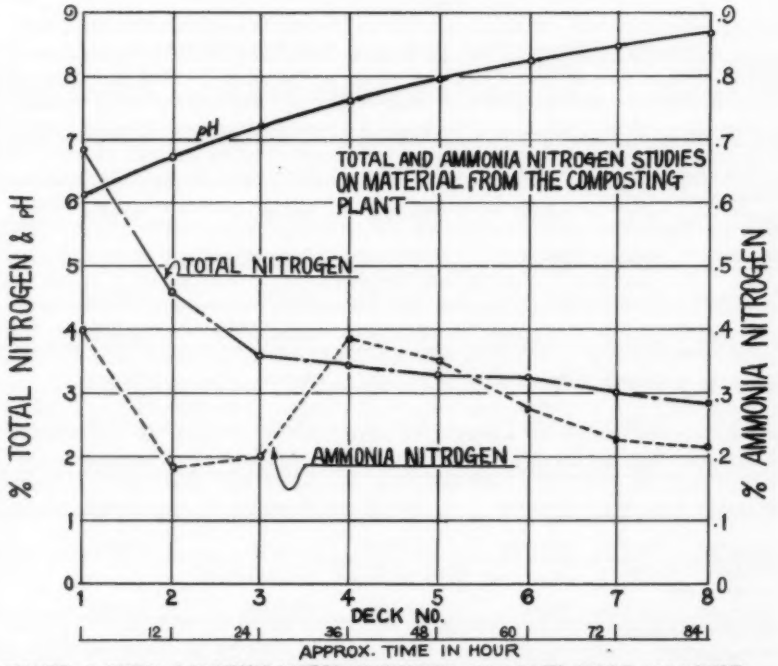


FIGURE-6 TOTAL & AMMONIA NITROGEN CHANGES IN MULTI STAGE DIGESTOR

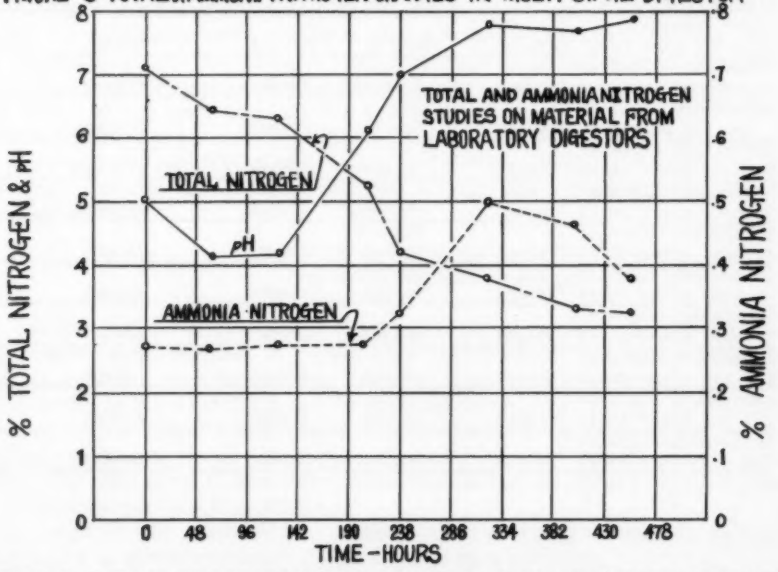


FIGURE-7 TOTAL & AMMONIA NITROGEN CHANGES IN BATCH TYPE LAB. DIGESTOR

TABLE 4

A Summary of Carbohydrate Studies on High Rate Composting

Sample type and location	Cellulose & Hemicellulose	Starch	Disaccharides	Monosaccharides
Raw Garbage	Present	Present	Present	Present
Dewatering Tank	Present	Present	Present	Present
Drain Fluid from Dewatering Tank	Absent	Absent	Present	Present
Digester - Deck 1	Present	Present	Present	Present
Digester - Deck 2	Present	Present & Absent	Absent	Absent
Digester - Decm 3	Present	Absent	Absent	Absent
Digester - Decm 4	Present	Absent	Absent	Absent
Digester - Decm 5	Present	Absent	Absent	Absent
Digester - Deck 6	Present	Absent	Absent	Absent
Digester - Deck 7	Present	Absent	Absent	Absent
Digester - Deck 8	Present	Absent	Absent	Absent
Windrow compost - layer above Actinomycetes layer	Present	Present	Present	Absent
Windrow compost - layer below Actinomycetes layer	Present	Present	Absent	Absent
Windrow compost - layer containing Actinomycetes layer	Present	Absent	Absent	Absent
Laboratory digester at start	Present	Present	Present	Present
Laboratory digester 6 hrs. after start	Present	Present	Present	Present
Laboratory digester 18 hrs. after start	Present	Present	Present	Present
Laboratory digester 30 hrs. after start	Present	Present	Absent	Absent
Laboratory digester 47 hrs. after start	Present	Present Absent	Absent	Absent
Laboratory digester 59 hrs. after start	Present	Present & Absent	Absent	Absent
Laboratory digester 71 hrs. after start	Present	Absent	Absent	Absent
Laboratory digester 122 hrs after start	Present	Absent	Absent	Absent
Laboratory digester 207 hrs after start	Present	Absent	Absent	Absent
Laboratory digester 336 hrs after start	Present	Absent	Absent	Absent

Preliminary Phosphorous Studies[6,6a]

One of the advantages claimed for the presence of organic matter in the soil is that leaching of plant nutrients is greatly reduced. This may be accomplished in part by holding the moisture like a sponge and in part by absorption. Also in the case of phosphorous and to a degree with nitrogen, leaching may be prevented by the actual changing of the elements themselves from soluble ionized salts to insoluble organic compounds or they may actually become a part of living microorganisms.

Studies were made at M.S.U. by composting ground garbage with P32 labelled triple super phosphate (48% P_2O_5) at the rate of 150 pounds of 20% super phosphate per ton of dry raw garbage. (This was equal to 30 lbs. of P_2O_5 per 600 lbs. of dry organic matter, assuming 70% moisture.)

Since the nitrogen level might effect the phosphorous change, 3 levels of 0,100 and 200 pounds added ammonium nitrate per ton of raw garbage were tried. By taking counts of the radio-activity of the)P32 left in the washings of the material the amount made insoluble in body protoplasm was obtained for each level of nitrogen. Results indicated that at the end of 336 hours of composting at 40°C in the batch continual stirring lab digesters, 96% of the phosphorous had been converted from the soluble leachable state into the insoluble organic state. No difference between the samples containing different amounts of nitrogen could be determined.

Preliminary Volatile Acid Studies[6]

In the composting process, as in the anaerobic digestion process, the excess concentration of volatile acids can be a serious problem causing severe inhibition or perhaps causing a complete breakdown of the process. In the anaerobic digestion of sewage sludge a slowdown occurs at about 2,000 ppm (0.2%) volatile acids and a complete stoppage occurs before a concentration of 5,000 ppm (0.5%) is reached. Fortunately the composting process appears to be much less sensitive to volatile acids and concentrations of 10,000 ppm (or 1.0%) do not seem to cause any serious inhibition.

Mention should be made that the volatile acid test at M.S.U. had to be accomplished with particular care including titration under an atmosphere of nitrogen to obtain reproducible results. Results are calculated from the following formula:

$$\% \text{ Acid} = \frac{\text{Vol. NaOH x Normality of NaOH x } 8.58}{\text{Dry wt. of sample in grams}}$$

The test measures the sum of the volatile acids and the volatile salts. The results are presented in Figure 8 for both a typical run on the pilot plant and a typical run on a batch type laboratory digester. The detention time for the 8 decks in the pilot plant can be assumed to be about 4 days. If the rise and succeeding fall of a high concentration of volatile acids is an indication of passage of two stages of composting, it should be noted that the rate of digestion in the pilot plant is about five times that in the laboratory digester, that is, 4 days as compared to 20 days.

It might also be assumed that composting is probably incomplete as long as volatile acid concentration of 4,000-5,000 ppm persists.

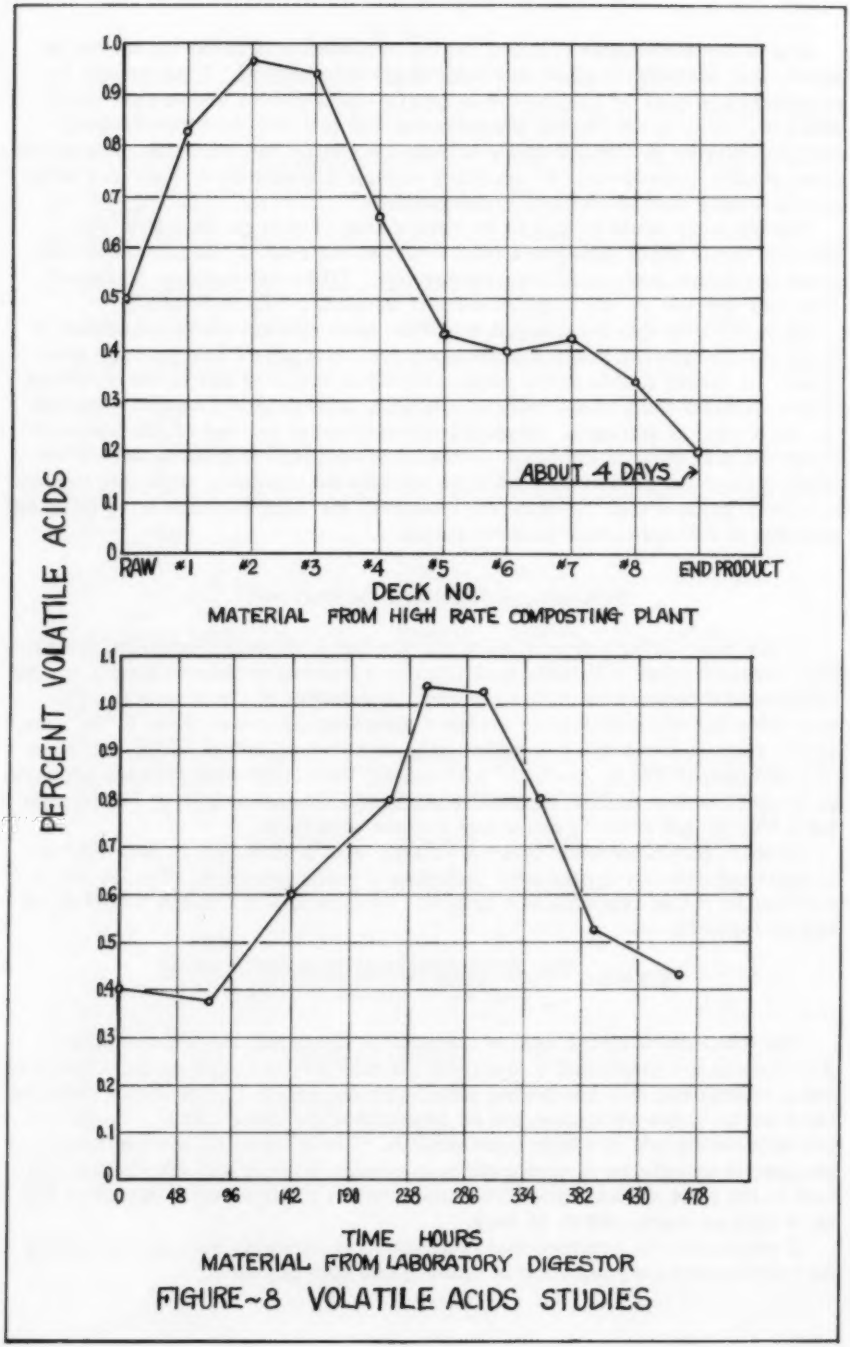


FIGURE-8 VOLATILE ACIDS STUDIES

Bacteria Population Studies(6a)

Although considerable work has been done at Michigan State University on the number and type of organism found under various conditions only a summary of these data will be presented here. Table 5 shows the predominating types of organisms found in laboratory batch experiments and various temperatures during the course of digestion.

There appears to be a fair correlation between bacterial count and oxygen uptake. This is evidenced by Figure 9 showing these two values plotted against time as well as showing them plotted against temperature.

Oxygen Transfer(10)

There are two ways gaseous oxygen can be supplied through the pore spaces into the mass of composting material: (1) by diffusion (2) by mass movement of the gas through the pores.

Mechanical stirring alone merely accelerates the above methods and should not be considered a separate method in itself. The concept of mass flow of a gas through a porous space will be dealt with in the following section. The relative importance of these two methods of gaseous transfer will also be discussed.

The modern theory of diffusion of gases in soils has been dealt with by a number of authors (24-34 inclusive). The special application of diffusion to composting was the subject of a doctorate thesis in December 1955 in the Civil Engineering Department at Michigan State University by B. J. Shell.(10) The basic research undertaken by Dr. Shell, under the direction of the author, represents, as far as is known, the only experimental work of its kind. Only a summary of the findings and the engineering applications can be presented in this paper.

In order to better understand the concepts of diffusion, let us discuss a specific example. Let us assume a 24" diameter by 12" high insulated drum filled with gently packed seeded ground garbage with a moisture content of say, 58%. The drum is open to the atmosphere on the top but otherwise tightly sealed. If the material is actively digesting, the oxygen contained in the pore space is used up rather quickly. Carbon dioxide and moisture are produced. Heat produced during this biological oxidation raises the temperature of the material.

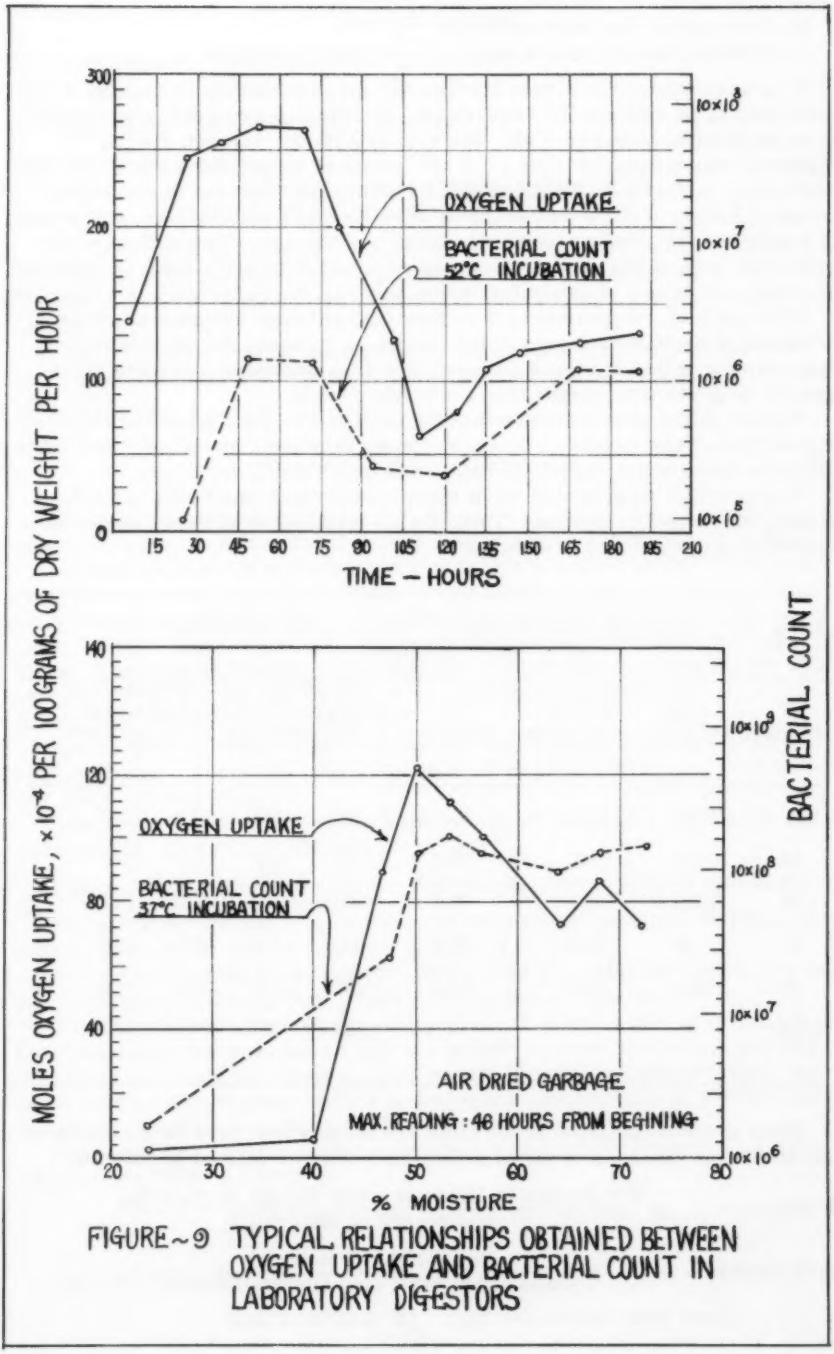
If it were not for the phenomenon of diffusion the 21% oxygen originally present in the pore space would be quickly replaced with carbon dioxide and composting, which is an aerobic biological process, would soon stop.

Diffusion may be described as a process of intermolecular bombardment and thus a continued intermixing of all gases present in a given space. Thus it appears that all gas molecules have a tendency to move in all directions and distribute themselves evenly in all spaces open to them. In our example, oxygen from the atmosphere diffuses into the lower pore spaces where it is converted biochemically into carbon dioxide. The carbon dioxide produced, on the other hand, diffuses from the lower pore spaces up to the surface and is dispersed into the atmosphere. The rate of total movement of a gas by diffusion is related as follows:

1. Directly to the partial pressure of the gas itself
2. Directly to the inter connected free air space available

TABLE 5
SUMMARY OF THE PREDOMINATING TYPES OF ORGANISMS FOUND DURING LABORATORY EXPERIMENTS

Temp °C	2 days	4 days	6 days	8 days	10 days	12 days
25	Pseudomonas	Pseudomonas 1/3 Flavobacterium	Flavobacterium	Flavobacterium	Flavobacterium	Mixed
30	Pseudomonas	Pseudomonas 1/3 Flavobacterium	Flavobacterium	Flavobacterium	Bacterium	Mixed
35	Flavobacterium	1/2 Bacilli 1/2 Actinomycetes	Molds (mixed)	Mixed	Mixed	Bacilli
40	1/2 Bacilli 1/2 Molds	1/2 Bacilli 1/2 Molds	Bacilli-Molds	Bacilli-Molds	Bacilli	Bacilli
45	1/2 Bacilli 1/2 Molds	Bacilli-Molds Actinomycetes	Bacilli	Bacilli	Bacilli	Bacilli
50	Bacilli	Bacilli	Bacilli	Bacilli	Bacilli	. . .
55	Bacilli	Bacilli	Bacilli	Bacilli	Bacilli Actinomycetes	. . .
65	Bacilli Actinomycetes	Bacilli Actinomycetes	Bacilli Actinomycetes	Bacilli Actinomycetes	Actinomycetes	. . .
70	10% Bacilli 90% Actinomycetes	10% Bacilli 90% Actinomycetes	10% Bacilli 90% Actinomycetes	Actinomycetes	. . .	. . .



FIGURE~9 TYPICAL RELATIONSHIPS OBTAINED BETWEEN OXYGEN UPTAKE AND BACTERIAL COUNT IN LABORATORY DIGESTORS

3. Directly to the gradient
4. Inversely to the length of travel
5. Inversely as the square root of the molecular weights

It is interesting to note that the free air space volume in our example was measured to be 33% and the relative rate of diffusion expected as compared to no restriction would be 0.25. The rate of diffusion through the full 12" thickness was measured to be 1.1×10^5 grams of 0_2 per minute per square centimeter of surface. On the basis of the maximum oxygen demand measured at Michigan State University of .0244 gr. o_2/minute/100 gr. dry weight of material only .0005 gr. can be supplied by diffusion. Thus diffusion supplies only 0.7% of the maximum oxygen required in this 12" depth of material. For only a 4" or a 2" depth of this same material the percentage is increased to 2.6% and 5.0% respectively. It is seen that although diffusion alone supplies only a small percentage of the maximum 0_2 needs during composting, it is also noted that layers of compost 2" - 4" in thickness are much more readily supplied with oxygen than are thicker ones.

Table 6 taken from the experimental work of Dr. Shell gives the engineer a good idea of the amount of 0_2 which can be supplied composting material by diffusion alone under varying conditions of depth and % moisture.

The material employed in all of these experiments was finely ground, separated, domestic garbage. Table 6 also gives some of the other physical relationships important to diffusion.

Table 6. Physical Relationships of Ground Domestic Garbage and Relative Diffusion Rates

% Moisture	Bulk Density	% Free Air Space	% Porosity	Relative Diffusion Rate For Various Depths of Material Compared with Free Air Space 2"	4"	8"	12"
41	.2830	44.5	75.5	.623	.567	.510	.397
50	.2540	39.0	78.0	.510	.442	.397	.318
58	.2443	33.0	78.9	.482	.414	.314	.250
64	.2557	28.0	77.9	.335	.272	.250	.227
70	.3070	22.0	73.4	.278	.193	.182	.056
Blank	-	-	-	1.00	-	-	-

Many of the terms used in the table are those which have been adopted in the studies on diffusion of air in soils. They may be defined as follows:

$$\% \text{ Moisture} = \frac{\text{Wet Weight of Material - Dry Weight of material}}{\text{Wet Weight of Material}}$$

$$\text{Bulk Density} = \frac{\text{Dry Weight of Material}}{\text{Volume of Material Wet (Before Drying)}}$$

$$\text{Porosity} = 1 - \frac{\text{Bulk Density}}{\text{Particle Density}}$$

Particle Density = Specific gravity of particles - (1.154 for dewatered garbage)

Free Air Space = Porosity (1-% Moisture)

Relative Diffusion Rate =

$$\frac{\text{Diffusion rate for condition described}}{\text{Diffusion rate for open container of same shape \& size}}$$

If it is desired to obtain the actual rate of oxygen diffusion the relative rates given in Table 6 need only be multiplied by the constant of 4.5×10^{-5}. The diffusion rate is then given in grams of oxygen per minute per square centimeter.

Porosity, as used here, means the free space occupied by both the water and the air. The free air space is the significant figure because it alone permits diffusion.

Oxygen Supply By Forced Air

Since diffusion alone supplies only 0.5 to 5% of the maximum oxygen requirements the engineer should look to forced air as a method of supply.

Laboratory experiments were conducted by the author to determine the resistance to mass movement of air through the pore spaces of ground garbage containing 58% moisture. The results plotted in Figure 10 show the lower 7" layer measured was compacted considerably more than the upper 7" layer. These experiments showed that for this particular material, air flows below about 15 cu. ft./min./sq. ft. were laminar while above 15 cu. ft./min./sq. ft. they were turbulent.

The maximum rate of oxygen utilization measured at Michigan State University during composting operations was .0244 grams 0_2/min./100 grams of dry weight of material.

Average ground garbage with a bulk density of 0.25 had a dry weight per cubic foot of $.25 \times 62.5 = 15.6$ lbs.

$$1 \text{ gram of oxygen} = \frac{22.4}{32.0} \times \frac{1}{28.3} = .047 \text{ cu. ft. under standard conditions.}$$

The air pressure and volume required for various depths of material composting at the peak rate of digestion are given in Table 7.

These calculations would indicate that forced air under low heads is a very practical method of supplying oxygen to composting material.

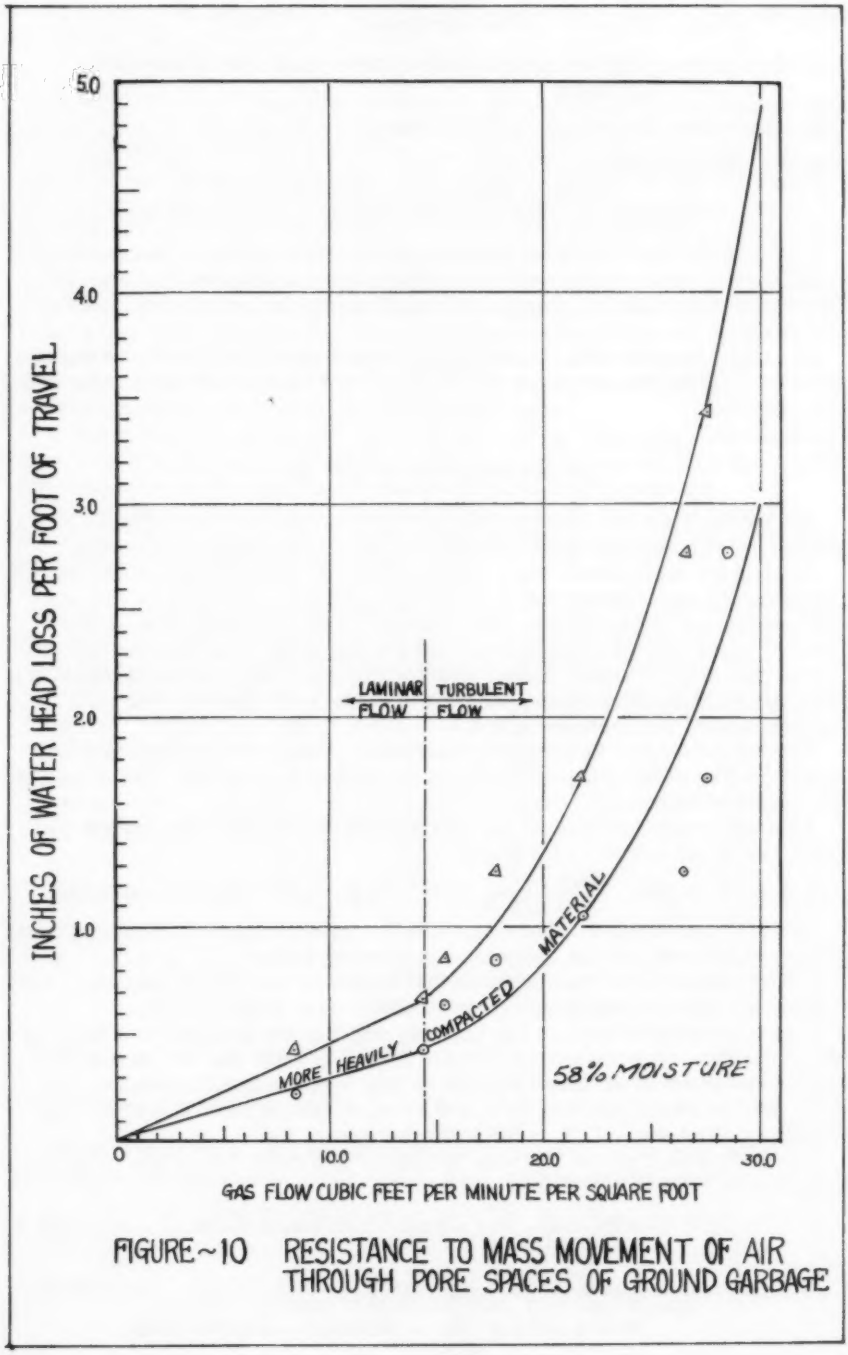
It is of interest to explore the chimney effect of the pore gas in a mass of hot composting material where cold air is free to enter the bottom and see how much air would be drawn through by this temperature differential. Assume outside temperature at 70°F and compost temperature at 170°F. Air density is .0764 lbs./cu. ft. at 60°F and 760 mm of Hg.

From Charles Law the increase in volume of a cubic foot of gas on being heated from 70°F to 170°F is

$$\frac{476 + 170}{476 + 70} - 1 = 1.18 - 1.00 = 0.18 \text{ cu. ft.}$$

The lift over a square foot of area is then -

$$0.18 \times .0764 \times \frac{12}{62.5} = .00264 \text{ inches water head.}$$



FIGURE~10 RESISTANCE TO MASS MOVEMENT OF AIR THROUGH PORE SPACES OF GROUND GARBAGE

Table 7. Air Pressure and Volume Required for Various Depths of Compost at Peak Rate of Digestion

Total Depth of Material	Cubic Foot Air Required per minute leaving 50% residential O_2 per sq. ft. of area	Head Loss Inches Water
1 foot	.77	.023 - .036
2 foot	1.54	.092 - .144
3 foot	2.31	.207 - .324
4 foot	3.08	.368 - .577
8 foot	6.16	1.47 -2.31
16 foot	12.32	5.9 -9.2

From Figure 10 this lift will produce a flow of .056 - .09 cu. ft. air per minute which is at 7 to 12% of the maximum required when the material is 12" deep. It is interesting to note that for this 12" depth the oxygen supplied by the natural chimney effect in hot compost is 15 to 25 times that supplied by simple diffusion from the top only, or 5 to 9 times that supplied from both top and bottom.

Summary of Suggested Design, Criteria and Needed Applied Research

Some of the design criteria suggested in this section are based on various experimental pilot plant data or laboratory results while others are based on observations resulting from experience, or in some instances only on the author's judgment. Certainly any composting plant designed today should be as flexible as possible and should be operated with the view toward gathering further accurate data useful to design rather than just as a plant for processing organic wastes. It is unlikely that initial plants will have their various stages in ideal balance but this does not mean they cannot be successfully and economically constructed and operated. Discussion of design criteria follows in the chronological order of the expected flow of material through a plant.

Materials Which May be Composted

Experience of various people in the field indicates that any non-toxic, finely ground organic matter with a carbon nitrogen ratio of less than 50 should compost, providing moisture content, temperature, pH, seeding and oxygen supply are reasonably controlled. This suggests municipal garbage or refuse (garbage and trash) or raw dewatered sewage sludge or any mixture of these. It also suggests a variety of farm and food production wastes or almost any difficult to dispose of organic wastes.

Materials with a high carbon nitrogen ratio should have nitrogen added in some form such as another waste higher in % nitrogen.

Receiving

For municipal wastes, such as garbage or refuse, receiving bins should be designed so that the material can be most economically and uniformly handled without causing delivery truck delays and assuring optimum plant operation. With the proper segregation at the source the plant problems are greatly simplified, but equipment can be constructed to handle all but the most cumbersome wastes such as old bedsprings, refrigerators, water heaters, auto tires, etc. At this phase of plant design, there is no substitution for inspection of existing equipment in actual operation or for manufacturer's experience and guarantees.

Sorting and Salvage

Here again design would vary greatly with the material to be handled. It would also be effected by the municipal pick up system and refuse ordinance. A study of the ordinance and pick up methods should be made before plant design is begun so as to produce a more economical and satisfactory overall waste handling approach than would otherwise be possible. It a single collection system is desired provision should be made to remove salvage or sorting material, undesirable for the grinding or the composting processes. Salvage may be made by hand picking as the material travels over a moving belt. Cans and other iron and steel may be removed by a permanent magnet pulley used as a roller on one end of this belt; however, difficulty has been experienced in obtaining metal free of refuse. Paper and cardboard salvage may or may not be provided for depending on local conditions. If this salvage is provided there are certain to be times of low market when this salvage operation should be abandoned in favor of producing more compost. It is believed that cities under 50 or 100 thousand will probably find that a revised refuse ordinance and collection method is all that is required or justified whereas a larger city may find installation of plans salvage operations justified.

Grinding

Although there are no commercial grinders available which have been especially developed to grind dewatered garbage or municipal refuse there are several commercially manufactured vertical swing hammer grinders which appear to do a reasonable job. Ruggedness and nonclogging qualities are essential. High speeds (1750 r.p.m.) and large diameters (40-44") seem to aid in making an efficiently produced fine grind. Further work with resistant alloy cutter blades is needed to lengthen the time for productive runs.

Dewatering of Separated Garbage

Even household garbage which has been wrapped in papers is too wet for ideal composting operations. If garbage cannot be more conveniently mixed with refuse or another drying agent, it is advisable to provide some efficient method of dewatering. One of the two well known continuous flow commercial processes was tried at M.S.U. for a period of four weeks with a high degree of success. Separated wrapped garbage with initial moisture contents of 80% plus could be dewatered to 60 to 65% by simple adjustment of the speed and clearance of the press discs. Liquids removed contained 9% solids but were

small in volume. They could be either passed to the sewer or used to control moisture in later stages of the composting operation.

Pre-Storage

If continuous flow mechanical digesters are to be employed it is advisable to provide for prestorage of the full days supply of ground garbage or refuse. This stored material also carries the process over the weekend at reduced speeds. Included with the storage tank should be a controlled feed mechanism to transfer the material from the prestorage tank to the digester on a slow continuous or intermittent basis. Experience indicates arching and clogging to be the two most important problems. Five feet round openings with steep sides (1-1/2 vertical to 1 horizontal) is about the minimum required. A bank of large diameter screws or an adjustable rotary turn-table have proven successful for this operation. If the material is to remain in this tank for more than 12-24 hours provision should be made for aeration by compressed air blown from suitably placed pipes in the tank. Drainage from the tank, unless provided for, may create a problem.

Mechanical Digestion

There are two sources of commercially designed digesters in America. One is a multi-deck, vertical cylinder. Material is agitated and aerated by plows on arms which are themselves turned from a central shaft. A modified model built along this general design was used for two years of pilot scale research at Michigan State University.

The second type of digester is a three deck horizontal unit having separate agitating and aeration mechanism for each level. Provision is made for increased aeration by forced air and blowers. It is believed that reseeding is better provided for than with the vertical unit. It is also felt that there is better control of the rate-of-flow-through of material.

In Europe a long rotating cyclinder type digester has proven satisfactory for mixed garbage and trash. Aeration is accomplished by the tumbling action of the material and with blowers. Wet, sticky, material would require pre-treatment to first bring about a nonadhering, porous consistency or anaerobic conditions might be expected.

The essential features of a good mechanical high-rate digester are:

a) Simplicity, large holding capacity, ruggedness and freedom from clogging.
b) Flexibility in operation especially in flow through time and air flow. (For best control employ a combination of agitation and forced air and blowers)
c) Slow continuous or frequent intermittent mixing and aeration of the material using minimum of power and equipment.
d) Feed back device for 2-10% reseeding in three stages.
e) Provisions for controlling the air flow, moisture and temperature of each of the three stages in accordance with its needs.
f) Post digestion, that is curing, drying and storage bins, should greatly increase the output and economy of high rate digestion plants.

A discussion of these features follows:
Flexibility in flow through time and aeration are important. Excess air

blown through the digesters with a fan is useful in cooling the process for temperature control more than in supplying the required oxygen. Temperature may also be controlled by water pipes or water jackets in contact with the metal portions of the digester. It is possible that too great an air supply will cause excessive, premature drying of the material before the desired degree of digestion has been accomplished. Provision to add moisture by spraying should solve the problem in a digester but is more difficult for a post digestion or curing bin. For plants digesting municipal wastes, holding capacities of 2-4 days in the mechanical digester should be adequate especially if an equivalent or longer time is provided in properly designed curing bins where the rate of digestion is appreciably less. Nitrogen losses can be reduced to a minimum by using sufficient air, not allowing the pH to go too high (keep around pH 7.0), keeping the total nitrogen values low or by passing exhaust gases over an acid contact chamber.

Curing, Drying and Storage Bins

The mechanical digester offers the most rapid and efficient method of composting available, yet because of its mechanical nature it is much more expensive per cubic foot of holding capacity than a combination curing, drying and storage bin. By the time compost has been discharged from a mechanical digester the rate of digestion should have been reduced to 10 or 20% of the peak rate and it should be porous and fluffy. It is uneconomical therefore to waste good digestion volume to continue digestion at a reduced rate when the same operation can be more economically accomplished otherwise.

Curing bins can be so constructed as to also serve as a drying and storage bin. The basic principle of construction is illustrated in Figure II. Cells 1 to 6 contain material previously removed, one to six days respectively, from the mechanical digester. The rate of digestion is expected to be reduced with time during the curing process. Thus air valves from the blowers are adjusted to give only sufficient oxygen to meet the needs of the material in each particular stage of digestion. It should be noted that starting on the 3rd day and continuing through the 6th, bins 3-6 have cool, dry air sucked from the atmosphere down through their material. This air dries the material to a point where biological activity is practically stopped. As the air passes through the material, it absorbs heat and moisture both of which may be beneficial to the early stages (first 1-2 days) of the curing process. All during this period the material need not be moved.

Operation consists only of adjusting the quantity and quality of air sucked or blown through the material. Laboratory and pilot experiments have been tried with only as much as a 30" depth of material but it is likely that depths of 6 to 8 ft. may be successfully used. Conveyors can be used for filling the bins while commercial loaders may be employed to empty them into trucks or railroad cars. Widths and lengths of bins can be adjusted for simplicity in construction and operation and for the desired plant capacity and ultimate storage needed. Further design criteria will be available after some actual plant operation has been experienced.

Conveying

Raw, wet, sticky, ground garbage is very difficult to lift with a conventional bucket conveyor because of clogging. Sloping belt or screw conveyors or tubular conveyors seem to more nearly overcome this problem. Rough

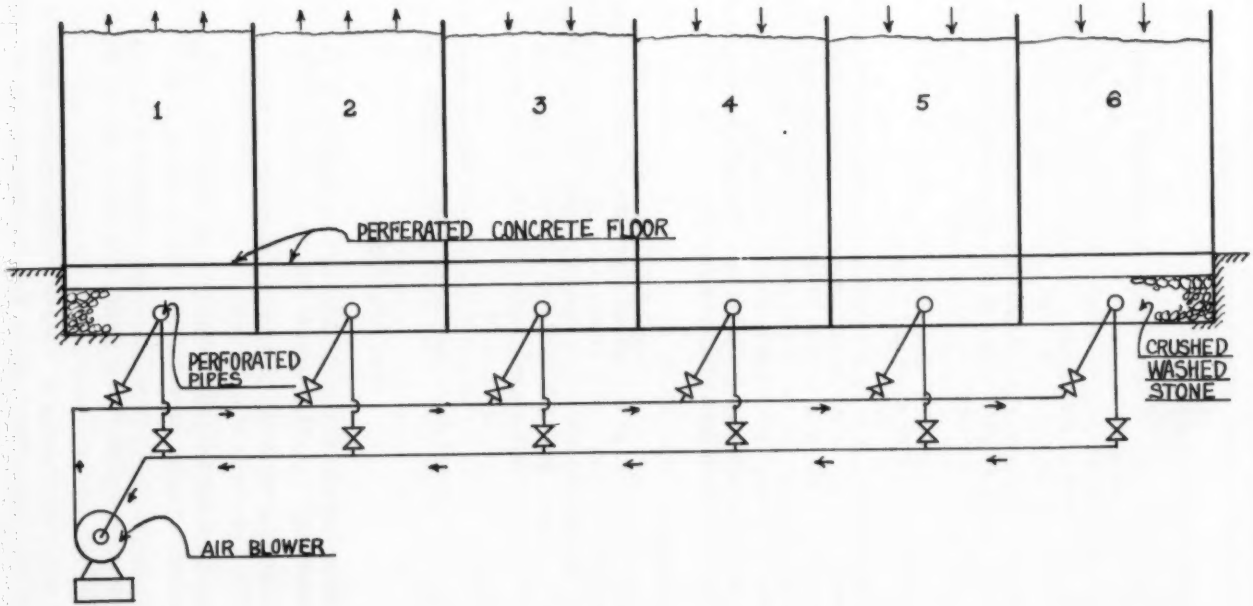


FIGURE-11 SKETCH OF RECOMMENDED "CURING" DRYING AND STORAGE BINS

trash or refuse is also difficult to handle except with especially designed screw or belt conveyors. Much more knowledge and experience is needed in the field of conveying these difficult waste materials.

Final Screening and Sacking

If the end product is to be sold only to farmers and nursery men it need not be dried below about 30% moisture, nor need it be screened nor sacked. If the backyard gardener is going to buy the material, moisture should be reduced to about 25-20% or less so as to greatly reduce further biological activity. Screening through a 1/2-1/4" mesh screen produces a more saleable end product. If sacks are to be stored for more than a few months they must be oiled, waxed or lined with a plastic liner, otherwise moisture may be picked up from the atmosphere and biological activity may destroy the sack.

Weights and Volumes of Garbage and Compost

Before any compost plant is designed it would be well to measure the physical properties of the particular material to be employed.

It is seen from Table 6 in section 14 that bulk density and free air space at various % moistures are two of the most important physical properties which should be measured for any new waste materials. The wet weight per cubic foot is also important. Until this and other information is obtained, accurate design computations cannot be made.

Design Procedure

It is quite possible to go through an elaborate procedure of computations for estimated changes in carbon nitrogen ratios, moisture produced and evaporated, volume and dry weight changes of the material, oxygen utilized and carbon produced, etc. It is felt, however, that to give this procedure at this time would be premature and would produce a false sense of accuracy of design.

It would be far better for this analysis to be presented along with the actual operating data of a full scale mechanical digester plant.

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WRITING ENGINEERING SPECIFICATIONS—FOR QUALITY, NOT PRICE[1]

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(Proc. Paper 1179)

SYNOPSIS

One of the major engineering problems in public works is specification writing. Too often stress is placed on price than on quality. There is a definite tendency to improve specifications so that quality is foremost and price is hindmost.

There is no better time to be specific than in speaking about specifications; and there is no better time to be highly technical than in discussing engineering specifications. In keeping with the first condition, attention will be focused on a very particular facet of the specification problem; a facet that has too long led to the puzzlement and frustration of the engineering turn of mind. Although it would be desirable to remain purely technical in handling this specific subject, there are so many human and political implications involved in it that a totally technological approach would be too ivory-towerish. The problem at hand is a doctrine known only too well, but too often forgotten or neglected in the rush of planning engineering projects for the bidding stage. It is the question of writing quality, not price, into engineering specifications, and, even more specifically of getting the quality desired for the price paid in processes, equipment and materials for public works projects. The question of getting quality in private engineering projects is left to more academic evaluation because there has been, unfortunately, some modicum of truth in the expressed view that private purchasers buy by choice while governmental agencies buy by chance.

If the engineering profession arises to the challenge which lies ahead in the field of public works construction to fit America for our future growth by

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2. Editor, Case-Shepperd-Mann Publishing Corp., New York, N. Y.

reviving and rejuvenating old cities and shaping new urban centers to serve ever-higher standards of the national economy, this "choice vs. chance" must be examined carefully and eliminated. It is the responsibility of the engineering profession which will build the bigger and better nation to make certain that the public dollar recognizes and purchases true value as does the private dollar. If anything, public funds must be even more carefully guarded to make certain that quality is purchased by choice, because price alone may fritter away funds which are a public trust. The billions of dollars that must be spent for public works must be wisely invested.

Examine the significance of this choice-chance situation. In order to protect public funds from diversion, dissipation and duplicity through favoritism, chicanery and all the other frailties of the human, laws were devised to require major public purchasing by competitive bidding and to award the project to the "lowest responsible bidder" who conforms with the specifications. This all-too-familiar phrase, coupled with the "or equal" clause in public works specifications, may protect the till from the person who would tap it for his own purposes but it may, at the same time, defeat its own purpose by over-stressing "price" and under-emphasizing "value."

The wisdom of such troublesome checks-and-balances in governmental financial law, as differentiated from private purchasing, cannot be judged superficially in the light of the better, more enlightened and more public-serving government of the mid-Twentieth Century. It must be judged with an eye toward the days of public-be-damned government; of haunch, paunch and jowl politics; and of ignorance of, and disinterest in governmental operations by the tax-paying public which was a far cry from the spirit that spilled tea into Boston Harbor to demand the right of representation and information, in and about its government.

Yet, there now stands inviolable the rigid law demanding open government buying, openly arrived at. And, there exists the hazard that the rigidity of the law may defeat good governmental purchasing—unless it is learned how to preserve the law and also maintain true economy in the public interest. And, therein lies the challenge of writing engineering specifications for quality and value, not price, for public works methods, mechanisms and materials.

Buying "Price" or "Value"

In an effort to arouse constructive interest in this problem and to catalyze the engineering profession into discussing its experiences in writing public works specifications aimed at overcoming this problem, an editorial, Do You Buy "Price" or "Value"?, was published in the March 1955 issue of WASTES ENGINEERING:

"It is true that governmental purchasing laws give some latitude to municipalities by requiring that bids be 'conforming' and that the low bidder be 'responsible.' The burden of proof, however, may be on the purchaser who may have to demonstrate, (at least for public opinion,) that the bid does not conform and the bidder is not responsible. Specifications can refer to specific materials or equipment but bidding must be left open to 'or equal' products."

In commenting on what has been referred to by some frustrated specification writers as the "or equal" loophole, this editorial pointed out that "John Ruskin, many years ago, had something to say about price and quality that is equally applicable today. He said, 'There is hardly anything in the world that

some man cannot make a little worse and sell a little cheaper, and the people who consider price only are this man's lawful prey'."

Ruskin's "lawful prey" was a highly apropos phrase to describe the engineer who is caught in the legal vise which was written into law to stay the hands of those who might seek to squander public funds. The provocative editorial was intended to learn if the engineering profession was aware of the problem of a one-sided price ticket that did not take quality into account; and if it knew the problem, what it was doing about it. The answers were not long in coming from manufacturers of sanitary engineering processes, equipment and materials, and from consulting engineers. Reputable manufacturers who offer quality products into which they have put materials of merit and the less tangible, yet essential ingredients of integrity, ingenuity and inventiveness strongly urged that engineering attention be turned to finding effective ways to overcome the shortsightedness and wastefulness of those who weigh only the dollar side of competitive price tickets.

Consulting engineers agreed that public works specifications may be irritating and inhibiting but they expressed confidence that carefully prepared documents could alleviate many of the problems of "competitive bidding," "lowest responsible bidder" and "or equal" requirements, without abrogating the legal aims of those who placed these restrictions on statute books to protect the public treasury. How then, can this be done? What must be the role of the engineering profession in achieving such a goal?

At the heart of the problem, of course, lies the legal requirement that major purchasing for governmental functions be carried out by competitive bidding. It may be assumed that this principle is so deeply inbred into national policies and into the philosophy of free and competitive enterprise that it will never be eliminated from major public works projects such as sewage treatment and water works facilities. Yet, it is not surprising that efforts are being made to soften the rigidity of municipal finance laws relating to bidding for materials, equipment and services of somewhat lesser scope.

For instance, the New York State Conference of Mayors and Other Officials has been waging a battle, expected to come to a head before the 1957 session of the state legislature, for elimination of competitive bidding if a local governing body votes, by two-thirds vote, that non-competitive bidding is in the best public interest. It is significant that mayors have raised official doubt about looking merely at the price tag, in the case of bidding. Whether their suggested procedure is fair and workable must be ascertained by state legislative, fiscal and legal authorities but their action has pointed out that officials, too, are concerned over the problem of getting what they want for the price they want to pay.

As suggested in the editorial on this subject, "The answer may lie in more positive specifications, spelling out exactly what the municipality wants in equipment, materials and supplies. There is reason for believing that some municipal misfortunes in buying stem from poorly written specifications or even indecisiveness over what is really wanted. If there is indecision, under the guise of 'open' specifications, it becomes unfair to blame a bidder who presents an offer based on the lowest quality that will meet the specification requirements. This, unfortunately, imposes a hardship on the manufacturer whose product exceeds the minimum requirement." In discussing this subject one runs the hazard of seeking solutions in phrases, if not in facts, just as broad, sweeping statements in specifications leave the desires of the engineer in doubt and place the bidder in the position of "going it blind" until the final intent of the specifications are jelled.

While the competitive bidding procedure and the "or equal" clause constitute a vicious cycle, the key to the viciousness may lie in the phrase: "more positive specifications, spelling out exactly what the municipality wants in equipment, materials and supplies." There is, indeed, indication that many miseries stem from what the editorial labels as "poorly written specifications or even indecisiveness over what is really wanted."

If this be so, there is an answer to the writing of engineering specifications—for quality, not price. The answer: Know what you want . . . Know what you are willing to pay . . . Write the proper quality into the specifications . . . Do not change the "ground rules" after the bids are received . . . Then accept the bid which conforms and which emanates from a "responsible bidder." If this does not give the project what it needs, the failure lies in the specifier, not the bidder.

Know What You Want—And Say So

If it is true that "or equal" means that the specification writer knows what the "standard" of quality or performance is, the responsibility rests on the specifier to really know. Glib words weaken the firmness of this responsibility. Nothing can be a substitute for knowledge.

Herein lies the rub. Behind knowledge of what is wanted lies the hard work which causes the distinction between "plagiarism" and "research" that some person with more wit than wisdom defined as "taking from one source" as distinguished from "taking from many sources." The pyramiding of specification cliches from one project to another—from one user to another—does not add authenticity or accuracy to the original.

There is no substitute for the real specification research which involves: (1) an analysis of equipment available from recognized manufacturers; (2) evaluation of the application of such equipment to the specific project; (3) fact-finding conferences with manufacturers; (4) preparation of exploratory specifications and distribution among potential suppliers to ascertain their views and their ability to supply; (5) a check of possible infringement of patent rights upon which manufacturers have staked research, development and investment.

There must be an open door through which flows manufacturers' information which the specifier may not be expected to possess in his own professional fund of knowledge. The great mechanization progress of America stems from the makers of equipment and of the electrical apparatus which are the heart of our substitution of what has been called "gears for grunts and switches for sweat. Through that open door will come data that can do much in writing "or equal" quality into projects, without sacrificing the original quality standard. The calibre of the engineering personnel attached to recognized equipment and materials manufacturers is our best guarantee of the ability of this type of team play to have beneficial effects on the true value of future public works projects.

The question has been raised: "What of the engineer's desire to specify something for which there is 'no equal,' or which, in other words, is the one and only such process, equipment or product available?" The answer here, too, is knowledge. If the engineer is to be the sole judge of the absence of "or equal" facilities, (and the courts appear to support the principle that expert knowledge is the basis of final decision), then that judging must be

backed up by judiciousness, not whim or caprice. The engineer must be able to demonstrate that what he wants is expressed in specifications that are firm and not brittle. The right of choice presupposes the responsibility to choose with knowledge and an understanding of what is available in the entire field.

The rigidity of any specification that says what it wants imposes another parallel responsibility on the specifier. He must not be a little man with powers of dictation; he must be a big person with powers of decision. Here is a man's job not to be assigned to a "boy."

The growing importance of specification writing in an era of new materials, processes and equipment has manifested itself in the organization of a technical institute of specification experts, established in 1948, "to promote and improve specification practices, to gather, compile and analyze information relating to or useful in the conduct of such activities; to engage in research and study of any and all problems and aspects of specification writing; and to establish and maintain the Institute as a clearing house of unbiased technical information on specifications for the fabrication and installation of construction materials and equipment."

These high aims cannot be achieved without a close bond between the maker and the specifier—a bond that can well stimulate higher quality, new development and, if anything, greater opportunity for competition on the basis of truly "or equal" products. In this spirit, specifications can become a new universal language—a new engineering Esperanto—which will substitute clarity for cloudiness, facts for fantasy—and which will help, not hamper progress in products.

The Challenge of Escalator Quality

There is a strong desire in the academic hope that some means might be found for writing specifications which set minimum floors under equipment and materials, with the offer of escalator premiums for quality above this base. How such a system of quality incentive could be achieved in the light of governmental bidding legalities is not clear. Yet, at the other end of the quality problem, the kind of specification writing that is based on knowledge will not condone the acceptance of material which does not meet performance requirements simply because its replacement would delay the job or otherwise inconvenience the project. The general tendency of specifications that stress "value" rather than "price" would be to raise, with each new day, the standards of quality without impeding the spirit of free and unbiased competitive bidding, and the rising "floor" of value would serve as its own escalator.

If engineers fail to blend the art and science of engineering with cold business practices which distinguish between buying for "quality" and merely looking at the price side of the purchase tag, they will deserve every defeat, every frustration, every weakness in public works construction which results from specifications that do not know what they want and, therefore, fail to provide what is needed.

Bigger and Better Public Works Projects

The challenge of today's public work projects will be magnificently overshadowed by the great developments of the next two decades. It can be

predicted with assurance that this nation will grow to a population of some 225 million . . . that the level of national production will rise by 50 per cent or more . . . that the standards of life will spiral with the rising economy . . . that the physical facilities must be expanded to meet this new national climate.

As a nation of urban dwellers, the greatest growth will concentrate in centers of population, rather than in the rural areas. New communities must be developed to become foci of progress; old communities must be rebuilt in the image of the future. New problems will require solutions: transit and transportation; better housing; more efficient commercial and industrial structures; better recreational facilities; brighter and better thoroughfares; dependable water supplies and pollution control installations; more efficient refuse disposal; dependable health and community cleanliness techniques. These visions must be translated into realities—and very soon. Everywhere, the task of urban rehabilitation and development has already been started; it must be thrown into high gear.

The engineering profession will be the builder of these better public works functions, which can be achieved by the construction of great public works projects into which will be poured billions of dollars, for structures and for mechanical and electrical equipment. It is essential that the engineers build in a manner that befits the greatness of this nation. The success of thousands of projects will depend on how well the engineer knows what he wants—and specifies it.

The precepts which have been enunciated, are known and practiced by the engineering profession. These practices augur well for the future because, if there were ever need for writing specifications for quality, not price alone, it is now, as we advance in the final half of a century of great national progress.

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COLOR IN INDUSTRIAL WASTES

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(Proc. Paper 1180)

SYNOPSIS

A review and summarization of the modern theories of color formation is presented. Special emphasis is placed upon the part chemical structure plays in color development. Commercial dyes are classified on the basis of their structures. The azo group of dyes, which represents about half of the commercial dyes manufactured today, was selected for experimental laboratory studies. The color of a typical azo dye was altered by utilizing scientific methods based on theoretical consideration of the dye's chemical structure. Reduction with $SnCl_2$ and salting with NaCl were most effective in reducing and changing the color of methyl orange, a monoazo dye.

INTRODUCTION

250,000,000 pounds of dyes at about \$1.00/# are produced and sold commercially each year in U.S. If those dyes were 90% consumed by the goods and paper they are used on, 25,000,000 # would still remain to be discharged into rivers each year. This is not only a tremendously extravagant waste, but also a detriment to our streams.

The presence of colored compounds in waste waters creates a somewhat different problem in stream sanitation than that of gross organic pollution. Colored streams affect the mental rather than the physical health of observers and users. It is already well-established that mental and physical health are closely related. For example, the medical profession claims that constant awareness of his condition and its eventual outcome can have a bad psychological effect upon the patient. In a similar manner, the presence of colored matter in streams makes the observer anxious for the safety and welfare of the downstream users. Thus, a stream relatively free from physical

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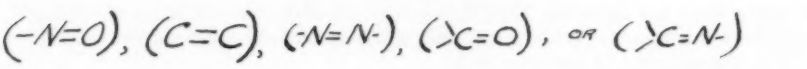
pollution but containing foreign colored matter may be classed as "polluted" in the eyes of the general public. It is then of the utmost importance to reduce the color of wastes being discharged to rivers. Chemical coagulation and adsorption methods have been used to some degree to remove color from various industrial wastes. Almost all treatment systems utilizing these methods have been based upon "cook book" laboratory results. Little attention has been paid by the sanitary engineer to the chemical structure of the color compound being treated.

Objective of Research

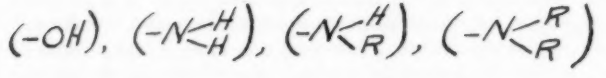
A review and summarization of the modern theories of color formation is presented. Special emphasis is placed upon the part chemical structures play in color development. Commercial dyes are classified on the basis of their structures. The azo group of dyes, which represents about half of the commercial dyes sold today, was selected for experimental laboratory studies. The main objective of this study is to demonstrate the possibilities of altering the color of a typical dye by scientific methods based on theoretical considerations of the chemical structure of the dye.

Theory of Color

White light (actually a composition of all colors) contains radiant energy in the form of photons. The photons, although they travel at the uniform speed of light, may possess various wave lengths or frequency values. Some radiant waves comprising white light are short and travel at a high frequency —others are long and travel at a low frequency. When radiant waves strike a liquid such as dye waste they are either unaffected by the liquid (therefore the liquid appears transparent) or are altered by the dye waste (and the liquid appears colored.) The chemical structure of the dye compound which absorbs certain wave lengths is the determining factor in the final color of the solution. Most modern theories agree that there are at least two important groups that must be present in a compound in order to develop visible color. One part of the color potential is an unsaturated group such as



and is generally referred to as a chromophore. The other part of the color potential in a compound is a saturated, salt-forming group such as



and is generally referred to in scientific circles as an auxochrome.

The oscillation of electrons from the chromophores to the auxochromes is currently believed to be the direct cause of color formation. The more powerful the auxochrome group in a given compound the more intense will be the resulting color. The activity of the auxochrome group depends upon freedom of its elections to interact with the chromophore group. Some researchers have gone so far as to list the auxochrome groups in order of their

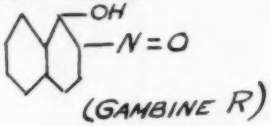
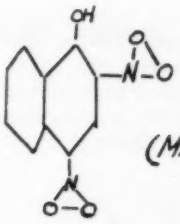
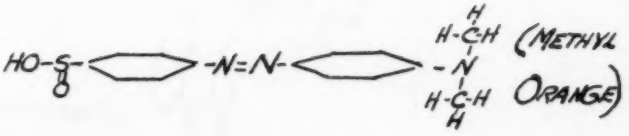
reactivity with hydrogen bonds at the weak end and substituted amino groups at the strong end. The important fact to remember concerning auxochromes is that any reduction in their ability to contribute oscillating electrons to the compound will reduce the length of the radiant wave which the compound exhibits at maximum transmission. This means that the resulting color will usually consist of shorter wave lengths and will be less objectionable when discharged to the river.

The deep theorists believe that the oscillation of electrons from one part of a compound to another produces a voltage drop. A specific voltage drop of a compound is often referred to as a characteristic "excitation frequency." If the voltage separation between energy levels of the molecule is equal to the frequency of the white light or other incident radiation, the molecule is capable of absorbing this radiation through a change in its electronic energy level. All of this simply means that if the compound possesses a specific structural configuration, it will absorb a specific part of the photons waves hitting it. This will then fix the final color of the compound.

It, therefore, becomes apparent that the first step is to ascertain the structure of a given colored compound. Then chemical and physical methods can be applied on a scientific basis to decrease the oscillation of electrons within the molecule. This should not be too difficult a task because the textile and paper dye chemists are constantly at work doing just the opposite; that is, increasing the oscillation of electrons to develop brighter, more saturated, and different hues in their dyes.

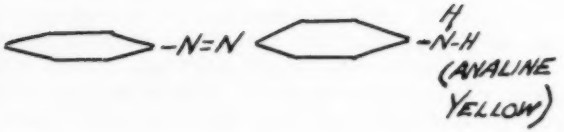
Commercial Dyes Classed According to Structure

The following is merely a summarized listing of a general grouping of the most important dyes. A complete coverage of the modern dye field will undoubtedly result in subgroups and even additional groups.

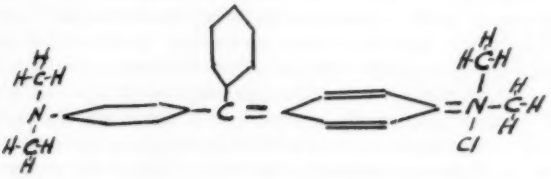
Groups	Characteristic structural formula
1. Nitroso	 (GAMBINE R)
2. Nitro	 (MARTIUS YELLOW)
*3. AZO	
A. ACID	 (METHYL ORANGE)

*May be subdivided into mono, di, and triazo dyes

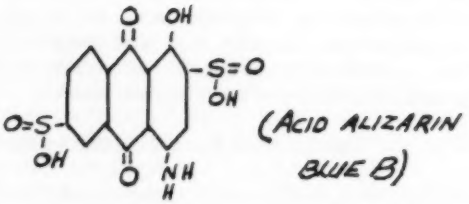
B. BASIC



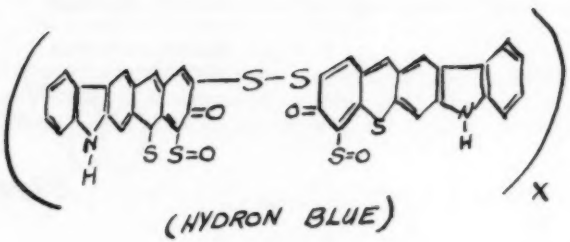
4. Triphenylmethane



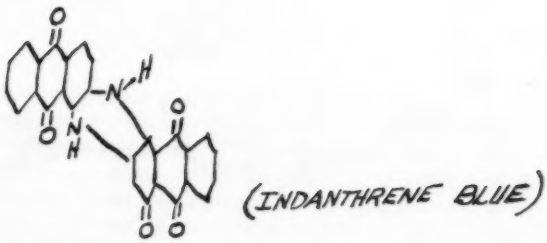
5. Anthraquinone



6. SULFUR



7. Heterocyclic



The Azo Group

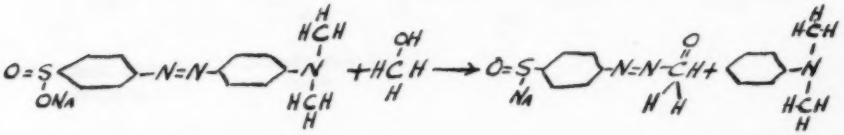
This group was selected because of its popularity in the dye field and its familiarity to sanitary engineers. The axo chromophore is the (-N = N-) and dyes are produced with this chromophore group and an aromatic ring, generally a benzene or napthalene ring. To one of these rings is attached either of the auxochromic groups OH or NH_2. The auxochrome must be placed in the ortho or para position to the azo group. Commercial dyes generally include sulfonic or carboxylic groups to increase the water solubility of the dye.

Theory of Reduction of Color of Azo Group

There are at least four prominant ways of decreasing the electron oscillation (or resonance) of the Azo-linked colored compounds.

1. Methoxylation
2. Alkali addition
3. Reduction
4. Salting

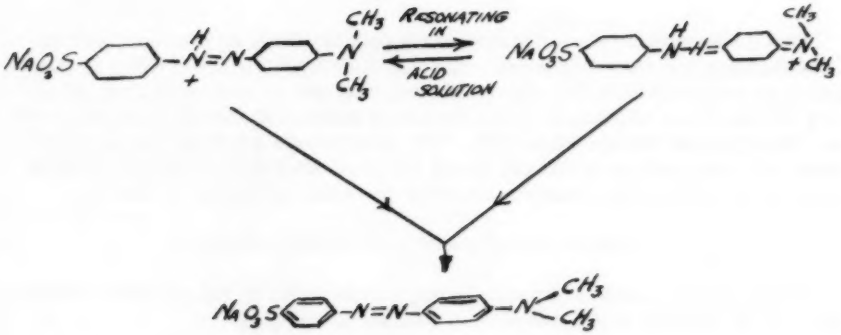
1. Methoxylation can be used to split one benzene ring from the compound and attaching the methoxy group (OCH_3) to the azide bond. This does not break the Azo bond. Such a substitution would decrease the resonance of the compound by simply shortening the length of chain. A shortening of the chain would result in a shorter wave length of maximum transmission (λ). The typical reaction of an Axo dye with methyl alcohol would be



METHYL ORANGE METHYL ALCOHOL

2. Alkali Addition

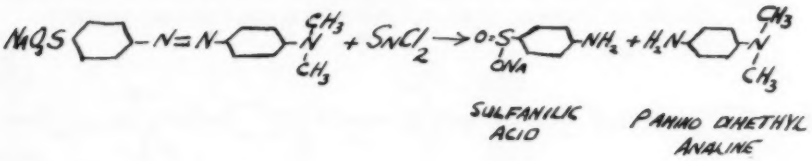
In acid solution the red form of methyl orange Azo dye possesses the movement of the unit plus charge between the nitrogen atoms and creates no restraining negative charge: hence, the higher degree of resonance and the resulting transmission of longer radiant waves. When caustic soda is added the resonating of the plus charge ceases and the compound becomes less active and results in the maximum transmission of shorter waves. This can be illustrated as follows:



With some dyes containing OH groups the alkali will convert then to (- O) groups with a resulting increase in dominant wave length.

3. Reduction

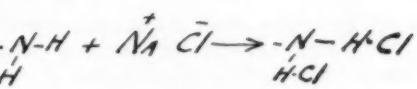
The addition of a strong reducing agent such as stannous chloride or hydrosulfite will break the Azo bond. Without a chromophore little or no color is possible according to the best theories. Such a reaction with methyl orange would be represented as follows:



4. Salting

The addition of sodium chloride to an Azo dye can have two effects both of which are capable of reducing the color.

a) inactivating the auxochrome groups by salting the groups such as



b) aggregation of the colloidal dye particles. With proper flocculation this will actually result in a precipitation of some or all of the dye. Removal of this precipitate by settling and/or filtration will result in a decrease in dye concentration in the remaining solution and thus a less intense color. The forces opposing aggregation are the repulsions exerted by the double layers surrounding the ionized sulfouric acid groups. The addition of electrolyte decreases the width of these double layers enabling the non polar areas of the molecule to approach sufficiently close for interaction by secondary forces.

Experimental Results With Methyl Orange Dye (Monoazo)

Methyl orange was selected for the laboratory experimentation because (1) it is a relatively simple monoazo type dye for which the chemical structure has been definitely ascertained and (2) because this particular dye is familiar to the sanitary engineer making laboratory water and sewage analyses. All four of the theoretical methods of altering the azo dye color were used in these analyses. The experimental results are presented in the following four graphs (Figures 1-4) and in Table 1.

It should be pointed out at this point that little effort was made by the author to perfect the four methods of altering the color. It is quite conceivable that additional experimentation will result in improved techniques for effecting greater color changes. In these studies the researcher was merely attempting to present evidence that the approach and methods could be applied. The methods used are described in the Appendix.

Color intensities were measured by visual comparison against standard color disks on the Hellige Colorimeter. Color changes were determined with Coleman Universal Spectrophotometer, Model 14.

TABLE I

[1]Color Intensities of Methyl Orange Dye Solution Before and After Alteration in Laboratory

Type Treatment	Original Color Intensity (ppm)	Final Color Intensity (ppm)	Color Reduction (%)
1. Methoxylation	90,000	90,000	0
2. Alkali	160,000	40,000	75
3. Reduction with $SNCl_2$	300,000	6,500	97
4. Salt	200,000	1,250	99+

[1]Color intensities measured by using Standard Methods Color wheel comparator.

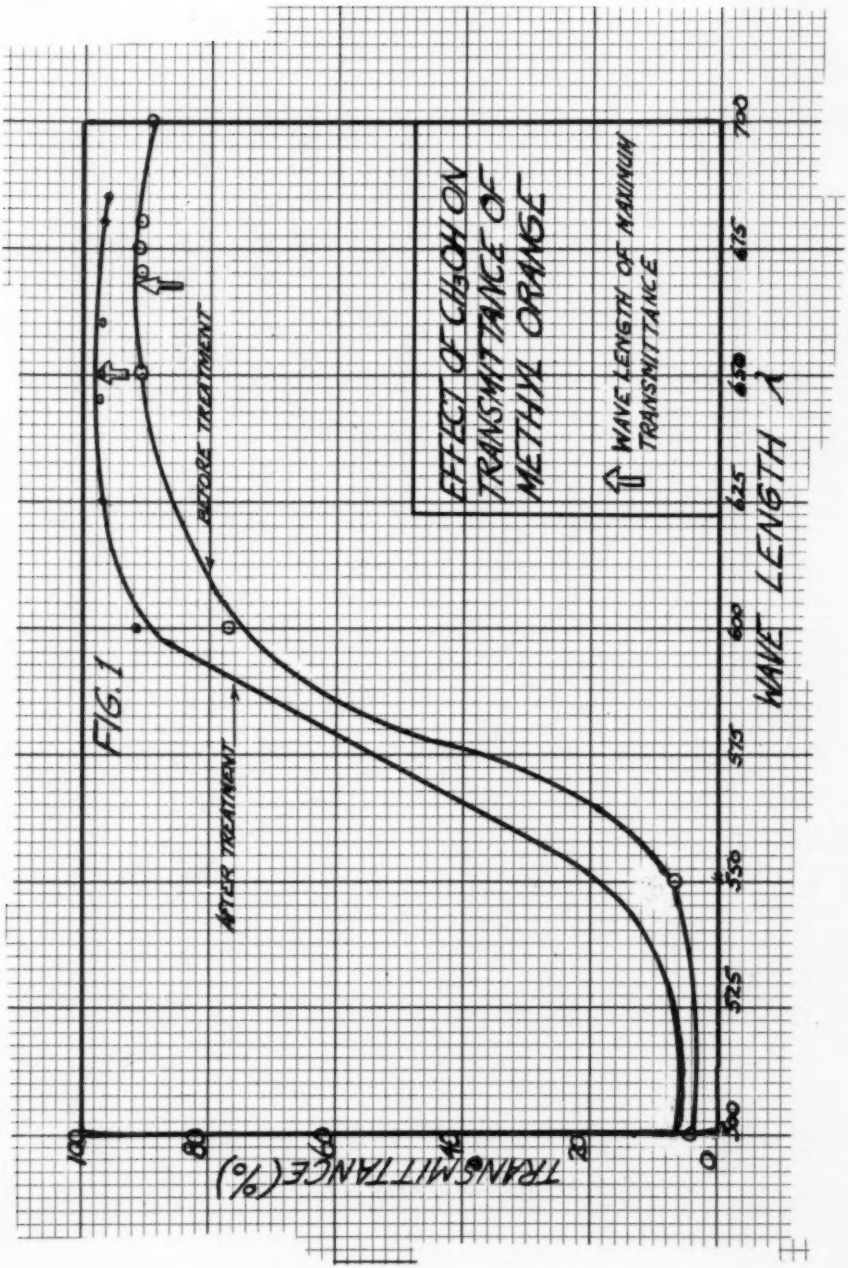
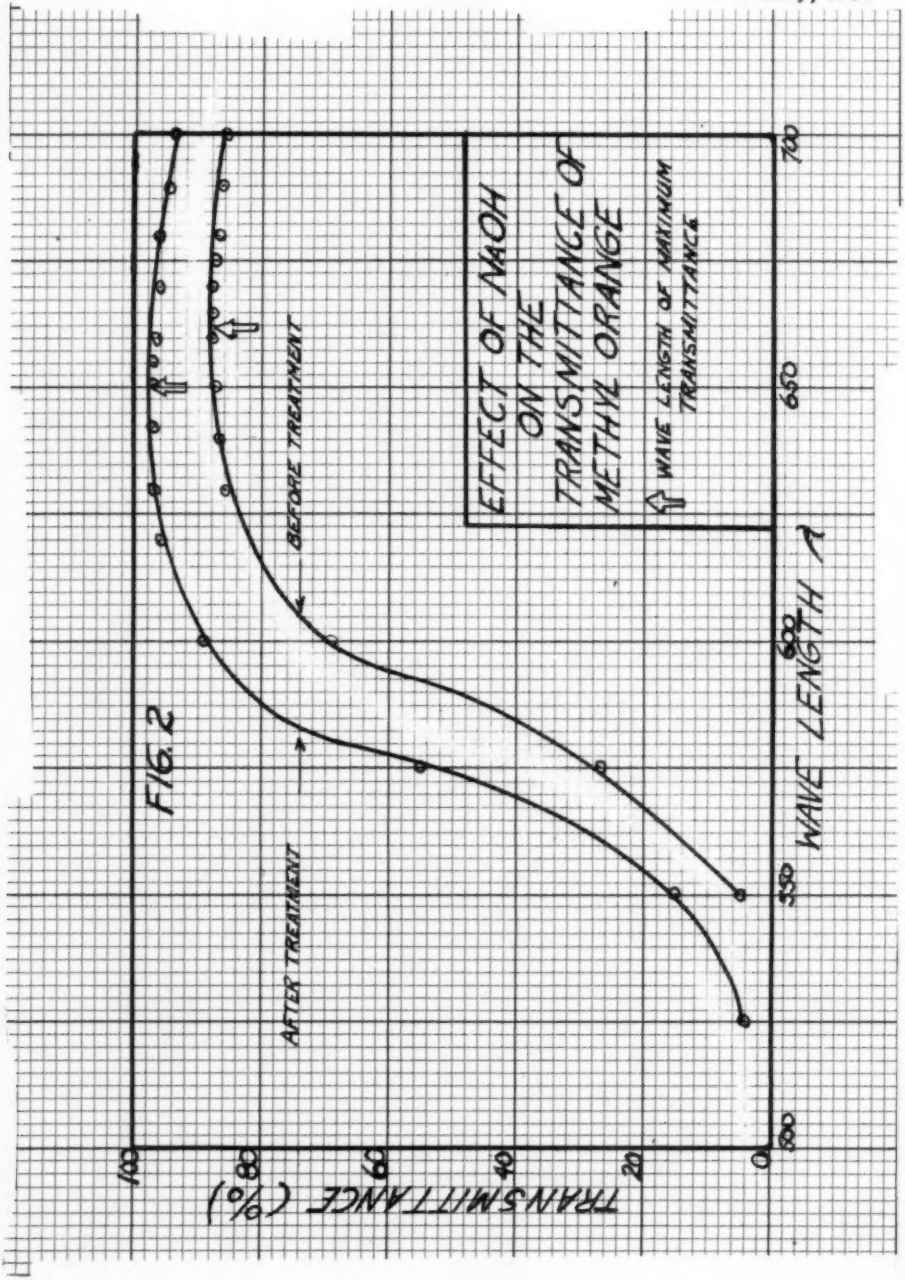

EFFECT OF CHLOH ON TRANSMITTANCE OF METHYL ORANGE
WAVE LENGTH OF MAXIMUM TRANSMITTANCE
BEFORE TREATMENT
AFTER TREATMENT
TRANSMITTANCE (%)
WAVE LENGTH λ
100
80
60
40
20
0
500
525
550
575
600
625
650
675
700

FIG 1


EFFECT OF NaOH
ON THE
TRANSMITTANCE OF
METHYL ORANGE
WAVE LENGTH OF MAXIMUM TRANSMITTANCE
BEFORE TREATMENT
AFTER TREATMENT
FIG 2
WAVE LENGTH mμ
TRANSMITTANCE (%)
700
660
600
550
500
100
80
60
40
20
0

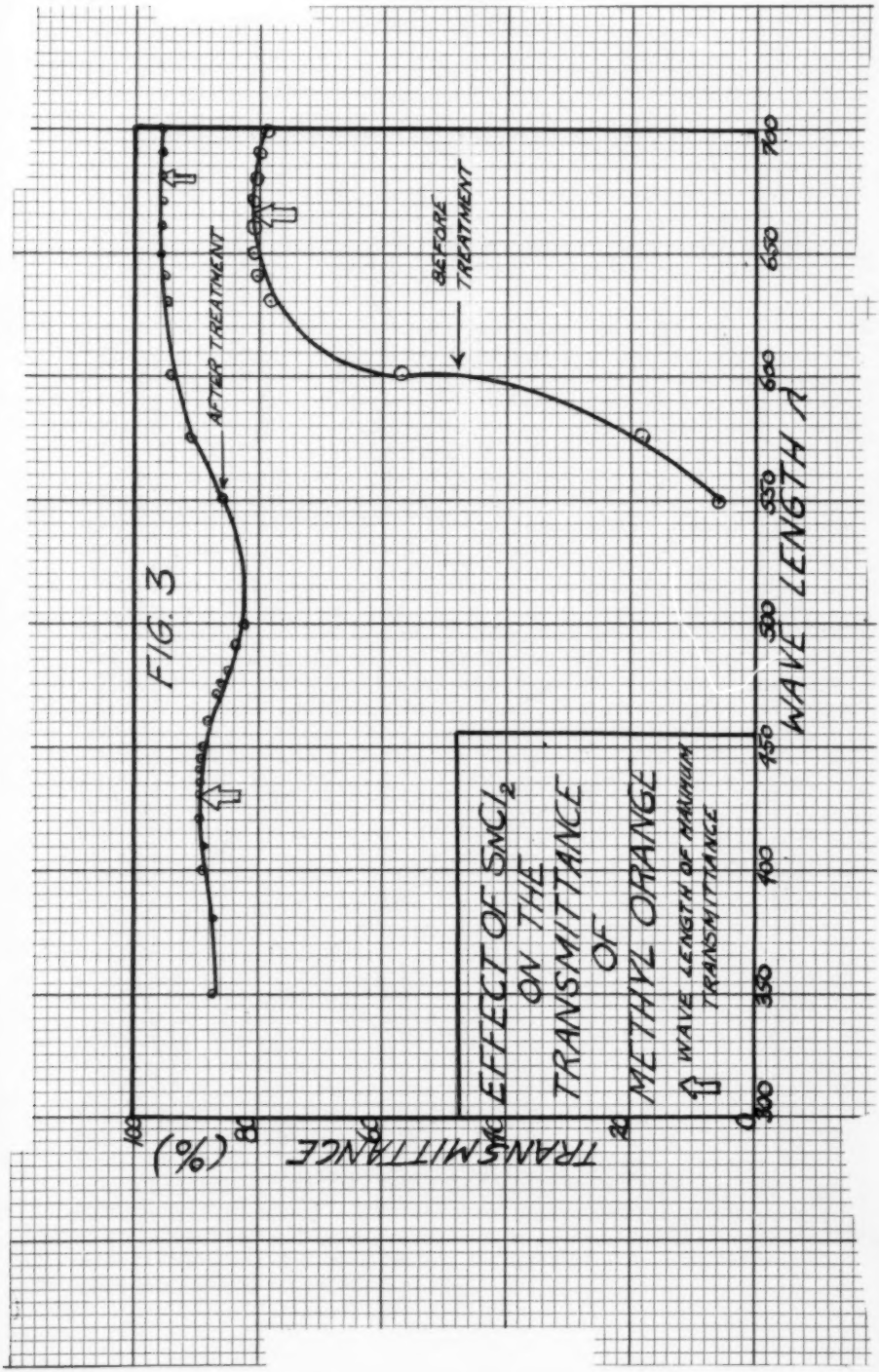


FIG. 3
EFFECT OF $SnCl_2$ ON THE TRANSMITTANCE OF METHYL ORANGE
WAVE LENGTH OF MAXIMUM TRANSMITTANCE
BEFORE TREATMENT
AFTER TREATMENT
TRANSMITTANCE (%)
WAVE LENGTH mμ
100
98
96
94
92
90
300
350
400
450
500
550
600
650
700

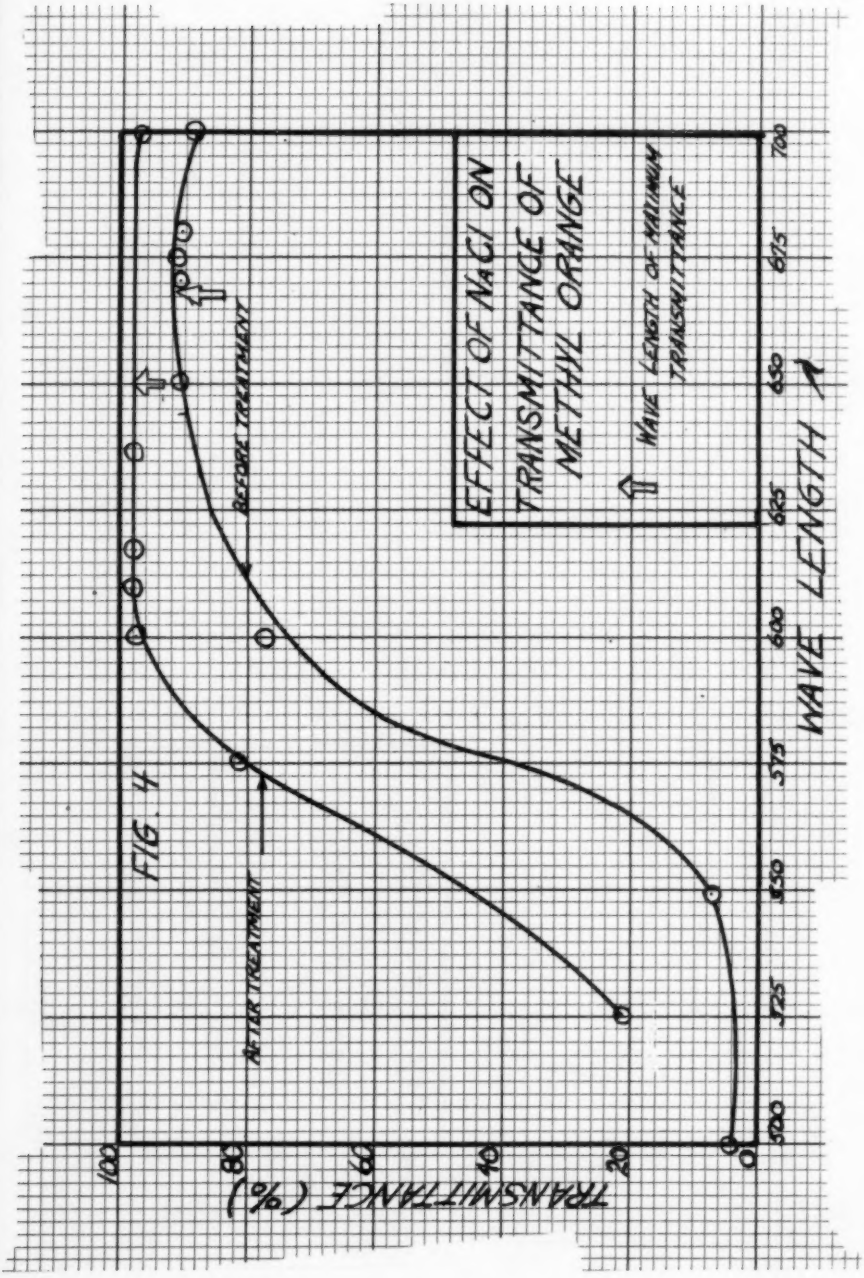

EFFECT OF NaCl ON TRANSMITTANCE OF METHYL ORANGE
WAVE LENGTH OF MAXIMUM TRANSMITTANCE
BEFORE TREATMENT
AFTER TREATMENT
TRANSMITTANCE (%)
WAVE LENGTH
100
80
60
40
20
0
500
525
550
575
600
625
650
675
700

FIG. 4

Discussion of Results

1. The addition of methyl alcohol to the methyl orange dye solution, although it did not appear to reduce the concentration of the dye (Table 1), shifted the wave length of maximum transmittance from an original value of 670 mu to a final value of 650 mu. (Figure 1). The change of 20 mu was significant and easily detectable by visual comparison of the two samples. Catalysts or other physical and chemical environmental factors may be necessary to induce this reaction to proceed more to completion. It is interesting to note (Figure 1) that at the most susceptible wave length to the human eye (575 mu) there was no difference in the transmittancy of the samples.

2. The addition of sodium hydroxide to the methyl orange dye solution resulted in a 75 per cent reduction in the intensity of the red color (Table 1). This was as expected from the theory described earlier and from practical experience with titration of methyl orange solutions with alkali in the laboratory. The dominant transmitting wave length was also reduced from 665 to 650 mu (Figure 2). This is proof that a structural change had occurred which resulted in a less intense color transmitting shorter wave lengths. At 575 mu the alkali treated methyl orange solution exhibited a transmittance of 55 per cent while the original methyl orange at this wave length transmitted only 27 per cent (Figure 2).

3. The addition of the reducing agent, stannous chloride, to methyl orange dye produced the greatest color change of any of the four methods. By visual comparison, the treated dye solution appeared slightly milky somewhat like fresh sewage as compared to the brilliant red color of the original solution. In short, there appeared to be no red color left. The color intensity was reduced 97 per cent (Table 1). The wave length of maximum transmittance was altered from an original value of 665 mu to two separate values of about 685 mu and 430 mu (Figure 3). This shows that there were two slight impurities left in the apparently colorless solution—one consisting of long wave lengths (685) and one of shorter wave lengths (430 mu). Both dominant waves had such high transmittancy values as to indicate little actual interference with these colors. Reduction of the azo bond not only separated the compound in to its two components but also gave rise to an almost colorless solution (white). This means that reduction processes such as, anaerobic digestion, would tend to decrease the color of dyes of this nature. Aerobic processes such as activated sludge could conceivably have little or no effect on the color of these dyes.

4. The addition of salt (NaCl) to the methyl orange dye solution resulted in a precipitate. When the clear solution was separated from its precipitate it exhibited a color intensity reduction of greater than 99 per cent (Table 1). On the other hand, the dominant transmittance wave length was only very slightly reduced from its original value of 665 mu (Figure 4). In fact, the transmittancy was so high in the dominant wave length region that it was not too easy to detect the actual peak wave length. It comprised values from 620 to 680 mu. The action of salt in reducing the color can then be ascribed mainly to a flocculating, aggregating, or precipitating effect. This method is often used by textile dyers to obtain more complete precipitation of dyes on fibres. Its application in color removal of dye wastes should not be overlooked.

SUMMARY AND CONCLUSIONS

The theory of color as it pertains to the structure of the molecule has been presented. Commercial dyes have been grouped according to similarities in their chemical structure. The azo group was selected for specific laboratory experiments designed to alter the color. Four methods for changing the color of an azo dye are discussed. The experimental results lead to the following specific conclusions.

1. CH_3OH reduced the wave length of maximum transmittance of methyl orange (an azo dye) but did not appear to reduce the intensity or concentration of the colored matter.
2. NaOH reduced the wave length of maximum transmittance of methyl orange (after filtering out the precipitate). At the same time the color concentration (as measured by the Hellige Colorimeter) was reduced 75 per cent.
3. $SnCl_2$ completely altered the color characteristics of methyl orange dye. The resulting solution resembled a very dilute milk in color and appearance. The intensity of color was reduced 97 per cent. Two dominant transmitting wave lengths (685 and 430 mu) characterized the treated dye solution.
4. NaCl only slightly altered the wave length of maximum transmittance of methyl orange dye. When the resulting precipitate was filtered out of the solution, the reduction in color intensity was more than 99 per cent.
5. Although no attention was given to perfecting the laboratory methods so that an economic analysis could be made, the reduction ($SnCl_2$) and salting (NaCl) processes appear most likely to be practical, feasible, economical, and effective.

ACKNOWLEDGMENT

The author is sincerely indebted to the National Institute of Health for sponsoring, not only this particular phase of color research, but also other current projects associated with color analysis and measurement.

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APPENDIX

A. Method of Color Alteration

1. Methoxylation

100 ml of methyl alcohol were added to 100 ml of methyl orange dye solution containing 1 gram of methyl orange per liter. This treated solution was compared to 100 ml of distilled water plus 100 ml of methyl orange dye solution (used as the raw dye of blank).

2. Alkylation

44 ml of 1N NaOH were added to 100 ml of methyl orange dye solution containing 1 gram of M.O. per liter. This was compared to a solution of 100 ml of M.O. solution plus 44 ml of distilled water. The treated solution after alkylation was filtered through Wattman No. 40 filter paper.

3. Reduction

200 mgs. of $SnCl_2$ were added to 100 ml of methyl orange dye solution containing 1 gram of M.O. per liter. The resulting mixture was refluxed for about 45 minutes and filtered through Wattman No. 40 filter paper. This was compared to a solution containing only 100 ml of methyl orange solution.

4. Salting

27.5 grams of NaCl were added to 250 ml of methyl orange dye solution containing 1 gram of methyl orange per liter. The resulting mixture was filtered through Wattman No. 40 filter paper. This was compared to a solution containing only 250 ml. of methyl orange solution.

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Proceedings of the American Society of Civil Engineers

ALLEGHENY COUNTY STORY OF SMOKE AND AIR POLLUTION CONTROL

Thomas C. Wurts,[1] and John J. Grove[2]
(Proc. Paper 1181)

SYNOPSIS

Since the 19th century the Pittsburgh area has been troubled by air pollution. The development of smoke and air pollution control in Allegheny County is an excellent example of what can be accomplished by cooperative efforts of an entire community.

The story of smoke control in this area begins in the first year of the 19th Century. Quotations from visitors at that time telling of the pall of black smoke which hung over the town, and further investigations indicate that the housewives preferred to heat and cook with coal that had been found in Coal Hill (Mount Washington) instead of the usual wood fuel. This resulted in the early christening of Pittsburgh as the "Smoky City." This appellation was highly descriptive of our atmosphere up to a few years ago.

A review of the attitudes in regard to this type of atmospheric pollution over the years is most interesting. In 1804 a letter was addressed to Council as follows: "I would be extremely sorry to be in any way the means of subjecting any of our fellow citizens to unnecessary and useless expense, but in this instance not only the comfort, health, and in some measure the consequence of the place, but the peace and harmony of the inhabitants depend upon the speedy measures being adopted to remedy the nuisance." This was the beginning of legislation in Pittsburgh against smoke.

Many ordinances were passed but none were really enforced until about 1910 under a reform administration one of the large steel companies was fined $10,000 for disregarding the head of the Smoke Bureau. This fine was appealed all the way to the Supreme Court of Pennsylvania and the ordinance was thrown out as class legislation. A few years earlier than this an effort

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2. Asst. Director of Allegheny Conference on Community Development, Pittsburgh, Pa.

was made to stop a certain operation by means of an injunction and Judge Frazier, President of the Supreme Court of the Commonwealth of Pennsylvania, refused the injunction on the grounds that, when you choose to live in an industrial community, you must put up with air contaminants resulting from such industrial operations. It was not until the formation of a cooperative group, known as the Allegheny Conference on Community Development, and the enactment of the ordinance for the City of Pittsburgh just prior to World War II in 1941 that real enforcement legislation was enacted. This ordinance, however, due to the War, did not become fully effective in the City until October 1, 1947.

About this same time, as the result of enabling legislation by the State Legislature, the Board of County Commissioners appointed an Advisory Committee with the duty of drawing up legislation to be effective County-wide.

The Committee was made up of chief executives of industry, of labor unions, and of citizens of the County and elected Dr. Edward R. Weidlein, President of Mellon Institute, as Chairman of the Committee. Dr. Weidlein appointed several subcommittees having chairmen as members of the main Advisory Committee. The other members of these subcommittees were non-members of the Advisory Committee but top engineering talent from industry covering the various subjects assigned to them.

These subcommittees did the foot work with the result that, when the ordinance was drawn up in final form some eighteen months later, it was a document drawn up by industry for industry, and was furthermore a document that did not have any unenforceable requirements. Where the answers were not known, the ordinance required that research committees should be formed for the purpose of studying the problems and coming up with the correct answers. This Ordinance became effective June 1, 1949. It has since been strengthened and amended August 15, 1955. In this latter revision cognizance is taken of some of the problems which have been solved as the result of research and, furthermore, of the fact that solutions will undoubtedly be forthcoming in the future.

Section 206 of the revised Ordinance reads in part as follows:

> "In the enforcement of this Ordinance the Director of the Bureau of Smoke Control is hereby authorized and given the power and the duty to promulgate procedural rules and bulletins. All such procedural rules and bulletins shall take into consideration the advancing state of the art of design and application of: fuel-burning equipment, industrial processes, inventions, accessories, and devices pertaining thereto in the determination of what economical and practical limits shall be established for full and proper compliance. Before issuing such technical procedural rules and bulletins, the Director shall seek and obtain the approval of the Advisory Committee. Etc."

This, in effect, permits the Director, with the approval of the Advisory Committee, to take advantage of future knowledge obtained and to revise the requirements of the Ordinance accordingly.

So much for the legislative side of the situation. Now what have been the accomplishments? It is safe to say that no one had any conception when these two pieces of legislation were enacted and made effective that industry would as wholeheartedly enter into the solution of the air pollution problem as they have.

Since 1949 practically all steam locomotives, both for main line railroads

and for inside plant operation, together with steam operated cranes, have been replaced with diesel units.

Similarly, on the rivers the old fashioned smoke belching steam operated paddle boat has virtually disappeared in favor of diesel towboats.

Blast furnaces, of which there are 29 in the area, used to have a habit of slipping thirty or forty times a month and now, as a result of more careful operation and better control of the raw materials fed into them, it is seldom that a blast furnace slips more than once or twice a month.

A problem that was thought to be insoluble was the extinguishment of coal wastes (gob) piles. These refuse piles from coal mines and coal cleaning plants were very susceptible to spontaneous combustion and, once started, continued to burn for years and to spread their smoke and fumes over many square miles of territory to leeward. As a result of research inaugurated by the Western Pennsylvania Coal Operators Association at Mellon Institute, and further as the result of some practical experiments by the coal operators, ways and means were found for extinguishing these piles and for preventing them from refiring.

Blast furnaces used for the production of ferro-manganese gave off prolific quantities of very fine particulate matter and, without being specifically mentioned in the Ordinance, this problem was carefully investigated and, as a result, electrostatic precipitators were installed on two blast furnaces of the Duquesne Works of the United States Steel Corporation for the elimination of this pollutant. A little better than 100 tons per day are removed from the effluent gases of these two furnaces.

Last April the United States Steel Corporation announced that they were about to proceed with the installation of electrostatic precipitators on their largest bank of eleven 250 ton open hearth furnaces at the Homestead Works.

In June, Jones and Laughlin Steel Corporation announced that they were making plans to immediately begin the installation of electrostatic precipitators on their several open hearth furnaces located on the South Side of Pittsburgh.

It goes without saying that all powerhouses in industry have been equipped where necessary with fly ash elimination equipment, and their stokers have been operated in such a manner as not to be smoky.

The net result of all this is that it has gone around the circle from the housewife, who in 1800 used coal and produced the "Smoky City" title, through the period of industrial uncontrolled atmospheric pollution, and now it is back to the details and to the point where it again becomes incumbent upon the individual to not pollute the atmosphere by burning wastepaper and garbage in the backyard or in back alleys, to the various communities to not have open refuse dumps where such material is burned, but to dispose of all of this type of refuse either by what is known as the sanitary fill where all of this material is dumped in a prepared ditch and then carefully covered over, or to dispose of it by means of an incinerator or perhaps even more modernly it will be possible to find ways and means of composting this waste material and making fertilizer out of it. Experiments along this line are underway.

Smoke reduction has also resulted in intangible benefits of almost unlimited scope and significance. It has helped to inspire civic, business, and industrial leaders, as well as the average citizen, with a sense of community pride that was once almost unknown.

Responding to the awakening of new faith in Pittsburgh and Allegheny

County, our citizens have brought about their greatest era of progress.

Fifty-nine (59) acres of commercial blight in the Point area of the Triangle, where Pittsburgh was first settled, have been cleared of all existing structures. In their place a 36-acre Point Park and an attractive new commercial district known as Gateway Center have completely revitalized this area. In other parts of the Triangle, 44 new office and business buildings have been built. At least $3,000,000 have been spent for exterior building cleaning in the County.

The new Greater Pittsburgh Airport is among the world's finest. The Penn-Lincoln Parkway, a 27-mile expressway through the heart of Pittsburgh, is nearing completion. Five colleges and universities—all located in Pittsburgh—are in the midst of their greatest period of physical expansion and curriculum development. The University of Pittsburgh Health Center is rapidly becoming one of America's finest.

The community has developed the Arts and Crafts Center, WQED Educational Television Station, Civic Light Opera presentations, and a unique new "Pittsburgh Plan for Art"; and greatly improved Carnegie Institute, Pittsburgh Opera, Pittsburgh Playhouse, Pittsburgh Symphony, and the Spring and Fall Flower Shows at Phipps Conservatory.

With a great deal of private assistance, more than 20,000 acres of outdoor recreation lands have been opened for public use in Western Pennsylvania. With public approval and financial help, the City has erected an excellent new Aviary-Conservatory, Children's Zoo, new swimming pools and recreation areas.

Smoke control has not been the direct cause of these exceptional achievements. But it has helped immeasurably to create the spirit and civic pride essential to carry forward a community development program of the magnitude Pittsburgh Allegheny County have undertaken.

DIVISION ACTIVITIES
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

NEWS

February, 1957

SED SECRETARY CASTER MEETS WITH KANSAS CITY SECTION

Secretary Caster was the speaker at the November 20 luncheon of the highly successful Sanitary Engineering Conference of the Kansas City Section. He spoke of the SED Division Affairs, particularly the Committee activity. In speaking of the five Task Committees, he said:

"The Task Committees are formed for a particular project, as the rewriting or preparation of a Manual. We have five such committees actively engaged in preparation of Manuals for the use of Sanitary Engineers and students, or those who are in consulting work, or those engineers who want to know what is a common adopted practice throughout the country on a particular phase of sanitary engineering. One of the committees is a Task Committee on the preparation of a Manual for sanitary and storm sewers. The workings of this Committee, more or less, is similar to the rest of the Manual Committees.

The most important part in the preparation of a Manual is to find a Chairman who is willing to sacrifice time, who is willing to endeavor to get his Committee members to work. Now, getting committee members to work takes many shapes and forms. You write to them in a nice way, you talk to them nice and then if that is to no avail you write nasty letters. Finally, a very seldom failing method used by one or two Committee Chairmen is that: 'If I do not hear from you or if I do not have any part of your section of the manual by such and such date, I will assume that you are no longer interested in having your name as part of the manual group, and will assign your portion of the manual to someone else who is more willing to take the job over.' This is a last resort method. Everyone loves to see his name in print, but it is not the intention of the Manual Committee Chairman to put anybody's name in a book who has not done any work. Consequently, this little reminder—that if as of a certain date the material is not received—seems to work very good. Normally, the man is one who has already accepted the job of doing the work and he's not one of the type who is going to sit back and not do anything, or he wouldn't have said he would do it in the first place. He probably has the material on his desk, all written up, or he has given it to his secretary to type up and she hasn't typed it yet, so it is one final reminder, and 95 percent

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of the time we find that the people send the material right on in, and it is in better shape than you would ever expect. Yes, the secretary and office force make or break committee members. Our thanks goes to the unceasing help from our fellow workers.

Now, after the various committee members of each section of the task group have submitted their material to their respective sub-chairmen, the material is brought together and circulated to all sub-chairmen. After they have had a chance to review the material from the other sub-chairmen, a meeting is held where from fifteen to twenty-five people come to the meeting, normally at their own expense and spend two or three long days in going over all of the material, each one criticising or recommending suggestions to be placed in that particular section they are reviewing. Stenographic help takes down these comments and at the end of the day presents to each sub-chairman copies of the comments discussed that day. The Section Chairmen, or sub-chairmen, take the material back with them, re-distribute it with the comments, and the committee members of that sub-committee rewrite their section of the Manual, taking cognizance of the comments made at the previous committee meeting. This proceeds two or three times, in fact, sometimes four or five times, until a manual has been edited to the satisfaction of all committee chairmen. The manual is then turned over to one or two men who re-edit the manual into one common language, because each one of us write different, each one of us talk different, so the manual is edited to a point that a common language is used throughout the manual. The correct headings are placed upon it, the sketches and the diagrams are put in the proper locations so that each chapter of the manual reads as a continuity of the whole manual. At the end of this period, the manual is then submitted in its entirety to all committee chairmen and to the Executive Committee for final review. After the Executive Committee has accepted the manual, it is then sent to the ASCE Home Office for the final editing and publication. The cost of the publication and the cost of the preparation of the manual is included in the cost per member after the manual is printed, whether it be two dollars ($2.00) or five dollars ($5.00).

Involved in the manual for the sewers, approximately eighty to ninety people are working on that manual. It is now in its final stages. The Manual on the Design and Operation of Sewage Treatment from an engineering standpoint has had two meetings and they are actively engaged in the final stages of their manual. The Manual on Sanitary Landfill is in its last stages. The Committee on the Manual of Incineration is now actively engaged in editing their parts of the manual. The Manual of the Revision of the Revision of Manual 19, Water Treatment, is slowly moving along. We had a hard time getting good committeemen who would work, but it is moving, and it will be approximately two years before that manual is completed.

A most active committee is the Committee on Sanitary Research. You'll notice in the publication short digests on research projects which have been edited down to a point where an engineer can understand the purpose of the research project and the application of that research project to everyday Sanitary Engineering.

Now, all committees need active members and if any of you, or all of you, are so inclined to give a few hours a week or a month to a committee, we will always be glad to place you on a committee that needs your particular speciality.

YOUNG ENGINEERS FOR TOMORROW

The second thought I would like to bring before you today is the training of young engineers, the shortage of engineers, and what we are doing or what we are going to do to encourage the youth to go to college and take up engineering, more especially, Sanitary Engineering.

At the Executive Committee meeting in Pittsburgh at the Annual ASCE this year, considerable discussion took place as to how we could encourage young people to enter the field of engineering. How we would make it attractive enough to get them to think of engineering as a profession. The subject was resolved in that we have a joint committee made up of several organizations under the leadership of the ASCE, the Committee known as the Joint Committee for the Advancement of Sanitary Engineering. The Committee has been working for the past few years on the Inter-Society Board. We felt that now the Inter-Society Board is a reality, it was moving along smoothly, that the Joint Committee for the Advancement of Sanitary Engineering would now be able to study the subject of how to encourage youth of today to go to school and study sanitary engineering. A resolution was directed to Chairman Boyce of that Committee for their consideration at their meeting after the ASCE meeting.

The problem as we see it is that of informing not only the youth in the grade schools and the first year or two of high school but also their parents as to the advantages, attractiveness, and the benefits gained by giving something to people—because that's what we do. We give something to people when we create sanitary facilities for the people's use and improving their health.

We are certainly trying to improve the stature of sanitary engineering, but it will be a long time before we are recognized as doctors or lawyers are today. In fact, we are in a different category. We give service to the general public rather than to an individual.

Through this whole ramification we must come up with some subject that is of interest and attractiveness to the youth. A great many of the engineering societies in the municipalities throughout the country either as a local section of the ASCE, or a local chapter of the NSPE, or as a technical council of the engineering societies are working with vocational guidance programs, where each year they round up students from all the high schools in their junior and senior years and bring them together for a day or an evening or two and talk with them about engineering—not only sanitary engineering but all engineering. Vocational guidance programs have been very successful in Cincinnati for the past eight or nine years and last year, as in previous years, Science Awards have been given where the students submit and demonstrate their ideas and working models of all phases of engineering and science. Over 800 students in the Metropolitan Cincinnati Area took part in this program last year for Science Awards, and scholarships worth $16,000 were given to those winners in the various classifications. Seven hundred representatives from the junior and senior classes of the various high schools in the Metropolitan Area met with the Engineering Society of Cincinnati, where all phases of engineering were discussed with them and then counselor groups where small groups of 10 or 15 students were told of a particular phase of engineering, as to the advantages of being a mechanical, electrical, civil, or sanitary engineer, or physicist, etc.

In all conversations throughout the country we have found that by the time the student is a senior it is almost too late to develop his line of thought, if it

has not already been developed in engineering, to change his trend of ideas to go to an engineering school. One main reason for this is that he has not properly taken the subjects during his freshman and sophomore and junior years as to math and science, and as a result, he is not eligible to get into the universities of today without extra courses being taken before he enters school. It has become the general consensus of opinion that we must go to the grade schools, the seventh and eighth grades, and hit the students there and also talk with them in their freshman and sophomore years to make the engineering profession attractive enough to those students that they will develop their curriculum along the lines necessary to graduation in high school so they can enter college with the proper credits and proper background along the engineering line.

Now, after the student has graduated from the university, we take him into our organizations, those who are fortunate enough to receive the privilege of the college student joining their organization today. The training has just started, his development has just started as to engineering practice and professional activities.

We must continue to train and develop his line of thought so he will stay in engineering rather than drop away into a more lucrative field of sales, insurance, or business. During his training period, we not only aid the young engineer in his development in his professional attitude, but at the same time we also aid ourselves. We may have to stop and look up a particular subject we want to talk about and think it over and develop it into terms that we can talk to the young engineer. So, at the same time, we are not only training the young engineer, but retraining ourselves, we might say.

When one of our young engineers comes to us and says he's leaving to go to a better paying job, if that job is in engineering (although we very much dislike seeing any of our men leave the organization), it is certainly a satisfaction to be able to say—'Well, so-and-so formerly worked for us,' and 'We had a hand in guiding his career today.' We do not say, 'If it weren't for us, he wouldn't be where he is today.'

In looking back over the past generation, the older engineers, every one of them can be proud of those men who worked for him and grew up in his organization and who have since left and have become recognized sanitary engineers in their own rights, either consultants, public health officials, state health officials, and municipal health officials. There certainly is a gratifying feeling in knowing that we have pushed—literally pushed those men along.

Now comes the time when we must push or 'pull' (probably is the better word)—'pull' the grade school and first and second year high school student upward by their boot straps to join with us in the engineering field."

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DID YOU KNOW THAT-

The Arthur Sidney Bedell Award was presented by the Federation of Sewage and Industrial Wastes Associations to J. E. Kiker, Jr., for outstanding personal service in the sewage works field.

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Dr. David B. Smith, Director of the Florida Water Resources Commission, has been elected President of the Florida Sewage and Industrial Wastes Association.

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Dr. F. A. Eidsness of Black and Associates in Gainesville was elected Director from the Florida Section to the American Water Works Association.

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UNIVERSITY OF OKLAHOMA STRENGTHENS WATER RESOURCES RESEARCH

A new agency has been established at the University of Oklahoma to coordinate all research dealing with water resources and usages in a state that continually must face drought conditions.

Director of the Bureau of Water Resources Research will be George W. Reid, CE, Associate Professor of Civil Engineering and Co-ordinator of Sanitary Science. Dean L. H. Snyder of the University of Oklahoma Graduate College will serve as Chairman of the Policy Board which will outline general procedure for the Bureau.

The Bureau of Water Resources Research will coordinate investigations and studies of water resources and undertake research and development concerned with specific and general problems relating to water supplies and consumption.

Oklahoma and other Plains states have become acutely water conscious. In many regions top soil has become powdery dust, and ground water levels are falling rapidly. The Bureau of Water Resources Research will develop information for use by state agencies.

Members of the policy board in addition to Dr. Snyder are Dr. Carl C. Branson, Director of the School of Geology and the Oklahoma Geological Survey; Dr. Ralph E. Olson, Chairman of the Department of Geography; Francis R. Cella, Director of the Bureau of Business Research; Dr. Carl D. Riggs, Director of the Oklahoma Biological Survey; and Joe W. Keeley, CE, Director of the School of Civil Engineering.

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George White of Wallace & Tiernan Company was elected Chairman of the Sanitary Division, San Francisco Section of ASCE. Bob Levy of the San Francisco Water Department is the new Vice-Chairman, and Sid Howard of Infilco is Secretary-Treasurer.

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Chris Medbury, a SED member, is the new President of the San Francisco Section of ASCE for 1957. Chris is employed by the San Francisco Water Department.

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P. H. McGauhey, Assistant Director, Sanitary Engineering Research Laboratory, University of California, Berkeley, presided at a conference on Recreational Use of Impounded Water at Richmond, California, on December 13 and 14, 1956. The subject of the conference has been discussed

controversially throughout the State for the past two years. Some of the speakers at the conference were Harvey O. Banks, newly appointed director of the California State Department of Water Resources; Charles Gilman Hyde, Professor Emeritus of Sanitary Engineering, University of California, Berkeley; Frank M. Stead, Chief, Division of Environmental Sanitation, California State Department of Public Health.

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In the San Francisco Bay area, the new Air Pollution Control District has officially begun to function. At a recent hearing, evidence was presented to prove that an air pollution hazard existed in the Bay area. Plans now are being made for initial control measures.

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Emil Jensen, Chief, Division of Engineering and Sanitation, Washington State Department of Health, is now president of the Federation of Sewage and Industrial Wastes Associations.

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Gilbert H. Dunstan, Professor of Sanitary Engineering, State College of Washington, was re-elected to the American Sanitary Engineering Intersociety Board, Inc., as one of the representatives of the American Society for Engineering Education.

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DID YOU KNOW THAT-

On December 12, H. Loren Thompson, consulting engineer of Portland, Oregon, spoke to the University of Idaho chapter of Sigma Xi, on the water supply problems of the University and the City of Moscow. His organization has been making a study of this problem.

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The construction of a sewage treatment plant for Spokane, Washington, was given the green light with a decision, late in November, by the State Supreme Court, holding a petition to change the site to be in error. The city expects to receive bids on the plant late in January.

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The Eighth Annual Pacific Northwest Industrial Wastes Conference will be held at the State College of Washington, Pullman, on April 4 and 5, 1957. Proceedings of the seventh conference are now available from William H. Knight, Technical Extension Services, State College of Washington, Pullman, at a cost of $3.00 a copy.

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DOC SYMONS ASSUMES NEW POSITION

Dr. George E. Symons, Consultant and Technical Editor, discontinued his private practice on December 1, 1956, to become Executive Vice President and Editorial Director of the Scranton Publishing Co., Inc., of New York City and Chicago.

In his new position Dr. Symons will supervise all fiscal, production, and editorial operations of Water & Sewage Works, Industrial Wastes, Modern Highways, and books published by the Scranton Publishing Co., Inc. He will also supervise market studies and will be Co-Editor of the Reference and Data Number of Water & Sewage Works.

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The Kansas City Section of ASCE sponsored a very successful Sanitary Engineering Conference on November 19-20. In attendance were more than 200 persons interested in the field, including consulting engineers, city officials, industrial representatives, and student groups from nearby colleges and universities.

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W. G. Riddle, an SED member, is the incoming president of the Kansas City Section of ASCE succeeding Louis G. Feil. Other SED members of the newly elected governing body include L. W. Bremser, secretary-treasurer, and R. O. Davis, Member of the Board.

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The seventh annual Sanitary Engineering Conference at the University of Kansas will be held January 8, 1957. Meetings will be held at the Student Union Building.

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ORSANCO PRESENTS EIGHTH ANNUAL REPORT

The Ohio River Valley Water Sanitation Commission presented its eighth annual report to the Governors of the eight compact states in November. Detailing the emphasis being placed on industrial-waste controls, the report to the Governors says that 965 of the 1,438 plants discharging effluents into streams of the valley are complying with minimum requirements adopted by the Commission. This was cited as a tribute to the efforts of the eight states, whose limited resources and manpower have been hard pressed to keep pace with industrial expansion, as well as testifying to a responsive attitude on the part of industrial management with regard to its responsibilities.

"But neither the record, nor the tribute to the state control agencies and the industries who have made it possible, establish any basis for complacency," says the report. "Satisfactory control of industrial wastes will require more and unremitting effort. To this task the Commission is devoting major attention."

In this connection three comprehensive studies on water use impairment are now being completed. They deal with phenolic substances, salt and hardness. The investigations will provide the basis for Commission decision on the promulgation and execution of industrial waste control measures beyond minimum requirements already established.

Pointing up the Commission's continuing attention to water quality changes that may be associated with atomic energy developments, the annual report outlines results from radioactivity surveys. During the past year background radiation studies at 13 points on the Ohio River and at 21 locations on tributaries were initiated by the Robert A. Taft Sanitary Engineering Center of the Public Health Service to aid the Commission. The Public Health Service scientists stated that: "The water samples indicated no actual or potential hazard to the public health at this time. More complete evaluation of radioactivity levels will require additional sampling and the Sanitary Engineering Center will gather similar data for the river mud and biota."

Details are also given by an Atomic Energy Commission "preoperational monitoring program" in the vicinity of the power reactor that is being built on the Ohio River at Shippingport, Pennsylvania. Sampling and analytical work is being done by the industrial hygiene department of Westinghouse Electric Corporation, which is the operating agent for the Atomic Energy Commission. Site monitoring will be continued by the Duquesne Light Company after the plant is in operation.

The importance of safeguarding the quality of the Ohio River is dramatized in a section of the report dealing with water uses. More than two million people in 116 communities depend on the river for their water supply; each day some 259,000,000 gallons are purified for municipal use. Industries along the river are the really big users of Ohio River water. They require almost 10 billion gallons daily for cooling and processing purposes.

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NEW RESEARCH PROJECTS AT UNIVERSITY OF FLORIDA

Study of Secondary Sewage Treatment

An extensive investigation of the basic processes of secondary sewage treatment has been undertaken at the University of Florida. Radioactive isotopes will be used as tracer elements to follow the decomposition of complex organic components of sewage in the biochemical changes that take place during the various types and stages of secondary treatment. In this study tagged portions of the principal compounds found in domestic sewage—such as minerals, fats, carbohydrates, and proteins—will be added to the sewage, and the retention times of the radioactive tracers in the various units will be measured.

These experiments will be conducted on a pilot-plant scale, using the present pilot sewage treatment plant which is an integral part of the Sanitary Engineering Research Laboratory.

Air Pollution Study

An investigation of air pollution problems has also begun under the direction of Dr. E. R. Hendrickson, entitled "A Preliminary Study of the Air Pollution Problems of the Pulp and Paper Industry." It is proposed to study the

evolution, diffusion, and possible control of air-borne effluents from the pulp and paper industry. Initial studies will be concerned mainly with the sulfate process.

The chemistry and manufacturing methods of each step of sulfate pulping will be studied in an attempt to determine the nature and possible sources of materials which might contribute to pollution of the atmosphere. Particular attention will be paid to those compounds which are known to have in adverse physiological effect on man, domestic animals, or vegetation; which have a destructive effect on materials of construction; or which create an odor nuisance. After this initial information has been obtained, air in the vicinity of suspected unit operations will be sampled, in addition to sampling stack or exhaust streams. Concurrently with this work, new sampling techniques and new quantitative analytical procedures may be developed or modified.

Based on the information obtained during the first two stages, several existing installations will be placed under study. The climatology in the vicinity will be investigated. This will include past weather records of the area, as well as records to be obtained. Areal surveys in the vicinity of the selected plants will be used to determine the nature and extent of diffusion. The information derived from this sampling will be correlated with simultaneous climatological observations.

Through continuation and variations in these investigations, it is hoped that effective control measures can be developed, either by reducing pollution at the source or by isolating certain operations. This can only be considered a pilot project to point the way to additional necessary work or to indicate that no serious problems exist.

Taxonomy and Ecology of Iron and Sulfur Bacteria

The iron and sulfur bacteria play an important part in nature and are of considerable importance economically. These organisms are associated with such diverse activities as the formation of boghead iron and sulfur deposits in nature; the tuberculation and pitting of water pipes, as well as slime formations in other water works structures; malfunctioning of certain waste treatment processes; and in stream sanitation. Despite their obvious importance, little is known of their position in the scale of life.

The University of Florida is attempting to determine the precise taxonomic position of these organisms, in addition to their ecology and nutritional requirements. There is believed to be a possible linkage, phylogenetically, of the bacteria and the algae.

As rapidly as culture media can be developed, pure cultures of the iron and sulfur bacteria will be prepared. Their reactions to nutritional variations will be carefully investigated and the products of their metabolism determined quantitatively and qualitatively.

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SANITARY ENGINEERING RESEARCH AT THE UNIVERSITY OF MICHIGAN

Research in Sanitary Engineering at the University of Michigan is not only well rooted in the conventional fields of water, sewage, and industrial wastes, but encompasses an expanding activity in air pollution as well. The over-all research program is under the general direction of Professor Earnest Boyce, Member-ASCE, Chairman, Department of Civil Engineering.

Dr. J. A. Borchardt, Associate Member-ASCE, Associate Professor of Civil Engineering, supervises the research program involving water, sewage, and industrial wastes. A research project delving into the basic chemical processes of water treatment has been underway since 1951. Present interest is primarily focused on the mechanism of chemical coagulation.

Stream pollution studies include the Huron River Study which is aimed at determining the capacity of this stream to assimilate nutrients. Basic concepts in productivity as well as the precipitation and fixation of essential elements are involved.

The use of oxidation-reduction potentials for the control of biological waste treatment systems is now being investigated. Present emphasis is directed toward determining whether oxidation-reduction potentials have any application in the control of sludge digestion. The initial step involving the evaluation of electrodes has been successfully completed. Other investigations are concerned with the use of soil conditioning chemicals in the disposal of septic tank effluents, the evaluation of the cyanide-cyanate reaction in industrial waste disposal applications, and the effect of detergents in digestion processes.

Air pollution research in the field of stack design has been carried on under the direction of Professor Robert Sherlock, Member-ASCE, Professor of Civil Engineering, for a number of years. Professor Sherlock has been successfully using a wind tunnel for the purpose of checking the adequacy of stack installation design. A Meteorological Division has recently been established within the Department of Civil Engineering under the direction of Dr. E. W. Hewson, Professor of Meteorology. Dr. Hewson is supervising several air pollution research projects sponsored by industry and is co-director of an interdisciplinary study of atmospheric pollution by aero-allergens being conducted by university faculty members in botany, internal medicine, and public health under the sponsorship of the National Institutes of Health of the Public Health Service.

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PROFESSOR BOYCE RECEIVES CERTIFICATE NO. I

Earnest Boyce, Professor of Sanitary Engineering, University of Michigan, and former Chairman of the American Sanitary Engineering Intersociety Board, has been awarded Certificate No. 1 by that Board. He thus becomes the first sanitary engineer to be certified by this Engineering Specialty Board. He served for many years as Chairman of the Joint Committee for the Advancement of Sanitary Engineers, which organized and incorporated the Intersociety Board, and served as the first chairman of the Board.

The first certificates were awarded at the October 1956 annual meeting of the Intersociety Board when more than 200 applications were considered. Approximately three-quarters of the applications were approved for certification without examination. Ten percent were rejected or held for further investigation. The balance were held for the first written examination to be given during 1957. Each successful applicant will be certified in one of the following five areas of "special qualification": Water Supply and Waste Water Disposal, Public Health Engineering, Industrial Hygiene, Radiation Hygiene and Hazard Control, and Air Pollution Control.

Officers elected for the year 1956-57 were:

Chairman: Thomas R. Camp of Camp, Dresser and McKee, Boston, Mass.

Vice-chairman: Ray E. Lawrence of Black & Veatch, Kansas City, Mo.

Treasurer: R. S. Rankin of Dorr-Oliver Co., Stamford, Conn.

Secretary: Francis B. Elder, American Public Health Association, N. Y. C.

Acceptance of sponsorship of the Board by the American Institute of Chemical Engineers was announced. Nominees for election to the Board of Trustees will be submitted by the Institute at a later date. This action brings to six the number of sponsoring organizations.

The American Sanitary Engineering Intersociety Board has been organized to elevate the standards and advance the cause of sanitary engineering. It is the first instance of a body organized for issuance of certificates to mark attainment of a high order of recognition in a specialization by any of the branches of engineering. Requirements for certification are a good moral character and a high ethical and professional standing, graduation from a recognized college of engineering, registration as a professional engineer, at least eight years' experience, and satisfactory completion of written and oral examinations. Until July 1, 1957, persons with 15 years' of satisfactory experience may be certified without examination.

Further information and application blanks from the Secretary, ASEIB, Room 1601, 33 W. 39th Street, New York 18, N. Y.

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NEW PUBLICATION

Publication of a new book written by three ASCE-SED members has recently been announced. This 86-page book is a publication of the University of Florida Engineering Series.

"Sewerage Planning" by Thomas deS. Furman, John E. Kiker, Jr., and David B. Smith. The aim of this book is to clear away misunderstanding about sewage treatment—its procurement, application, and operation—so that it will be looked upon as a vital and necessary service which enables us to lead healthier, happier, and more enjoyable lives. The publication is a result of several years' experience in a research project which approached the problem of waste disposal from several directions: (1) to examine the design criteria which are applicable to Florida conditions; (2) to investigate native Florida materials which may be used in waste treatment; and (3) to explain to city officials and public spirited citizens in simple everyday terms the problems involved and the methods used in the treatment of sewage. This book adequately fills the third objective of the problem. In addition to discussion the collection and treatment of sewage, chapters are included on financing and the role of the State Board of Health, the consulting engineer, and the contractor. Responsibility of the community for adequate operation after construction is thoroughly discussed.

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PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1113 is identified as 1113 (HY6) which indicates that the paper is contained in issue 6 of the Journal of the Hydraulics Division.

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c. Discussion of several papers, grouped by Divisions.

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